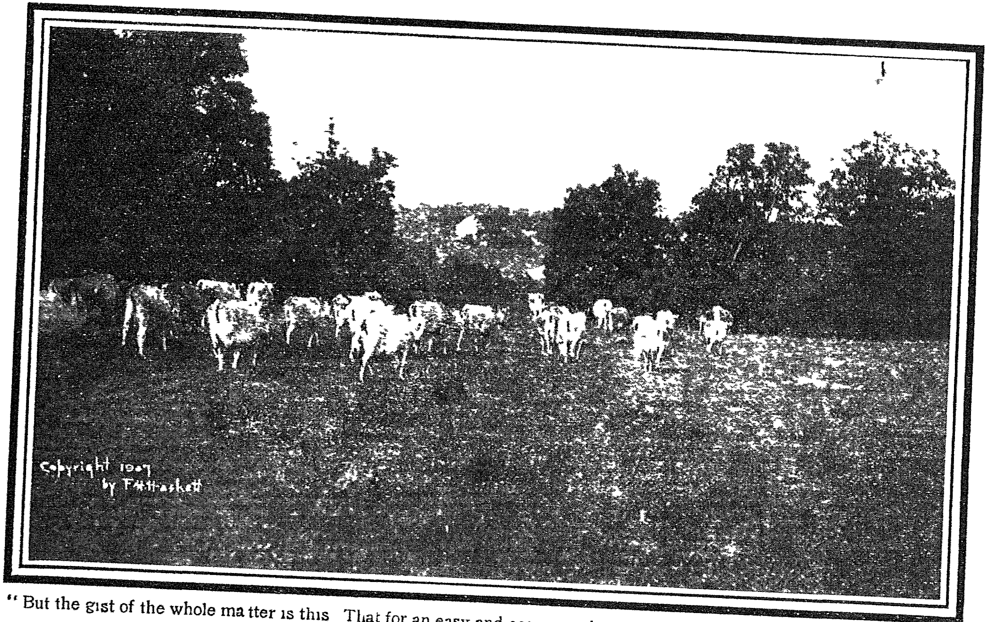

"But the gist of the whole matter is this That for an easy and economical method of maintaining the fertility of the soil there is nothing equal to the practice of dairy farming"

FIRST PRINCIPLES OF SOIL FERTILITY

By

ALFRED VIVIAN

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ILLUSTRATED

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"Ye rigid Ploughmen! bear in mind
Your labor is for future hours.
Advance! spare not! nor look behind!
Plough deep and straight with all your powers!"

RICHARD HENGIST HORNE.

"When tillage begins, other arts follow. The farmers, therefore, are the founders of human civilization."

DANIEL WEBSTER.

ACKNOWLEDGMENTS

The author desires to acknowledge his obligation to the following named persons for the illustrations found on the pages indicated Director C E Thorne, Ohio Experiment Station, 182, 230, 250, Director J. H Stewart, West Virginia Experiment Station, 112, 176, 177; Director H J Wheeler, Rhode Island Experiment Station, 246, 248; Professor C A. Mooers, Tennessee Experiment Station, 206, 216, 217, Director L H Bailey, Cornell Experiment Station, 187, 205; Professor F H King, Madison, Wisconsin, 62; L H. Goddard, Ohio Experiment Station, 147, 243, 245, Professor V H. Davis, Ohio State University, 103, Professor W. J. Frazer, University of Illinois, 159; F. H. Haskett, Columbus, Ohio, 28, 29, and frontispiece; M. Earl Carr, United States Department of Agriculture, 4; Orange Judd Company, 4, 39, 89, 120, 218 The line drawings are by Orange Judd Company's artist Mr B F. Williamson. Credit for the remaining illustrations, where not cited, is equally divided between Mr. A. B Graham, Superintendent of Agricultural Extension, Ohio State University, and the author.

PREFACE

This little book is intended primarily for home reading It is written, however, largely from lecture notes used by the author in a course in soil fertility given to winter course students, and, therefore, will be found to be a suitable text for short courses. It is an attempt to present in non-technical language a subject of great scientific and practical interest to the farmer. The subject of Soil Fertility is so large, that each phase of it could of necessity be only briefly considered in a small book, and the writer did not pretend to make the discussion of any topic exhaustive. For this reason some things have been omitted which might have been discussed with profit in a larger work. Only the more important facts concerning the maintenance of fertility have been presented, but it is believed that the statements so far as they go are in accord with the best scientific thought and practice of the day.

A certain amount of repetition has been purposely used in the text; for it is felt that in this way only can the more important facts be given the emphasis which they deserve, but it is thought that this method of treatment has not been carried to the point of monotony It is hoped that this book may find a little place in agricultural literature which is not already filled, and that it may be the means of leading a few earnest minds to a more extended study of this important subject of the fertility of the soil.

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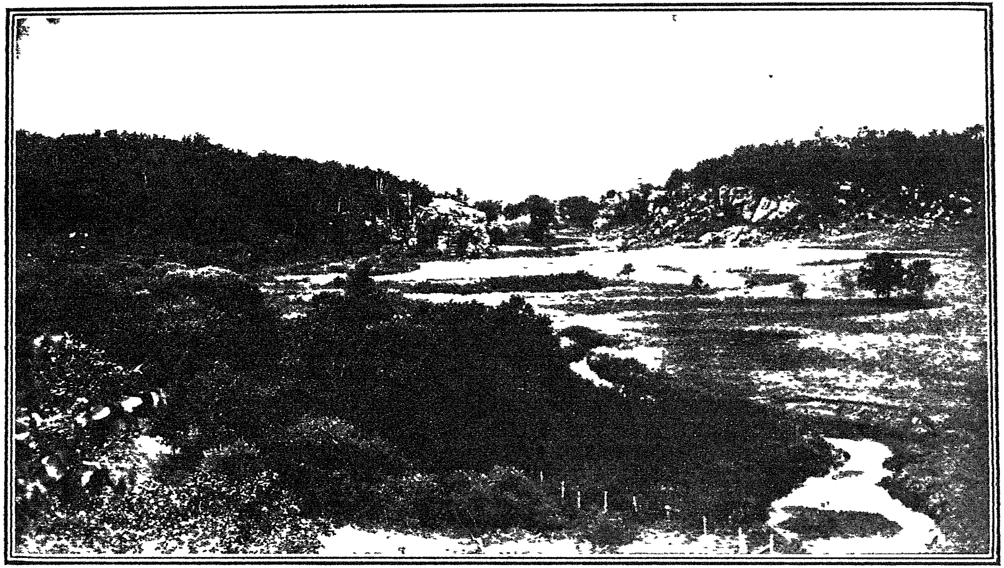
PART I

PLANT FOOD—ITS NATURE AND SOURCE



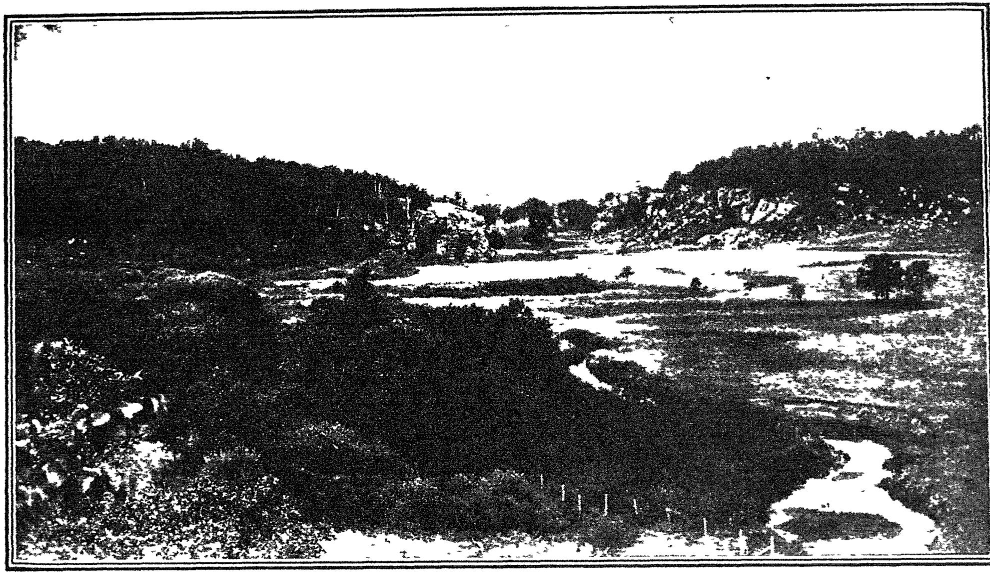
Running water is Nature's greatest sculptor. It carves out hills and valleys, and carries away the debris to form a soil in some other place

CHAPTER I

INTRODUCTORY

Farming is a business, and the successful farmer must be first of all a business man. He follows his vocation primarily for the money he can make, and like other business men should aim to get the greatest possible returns for the money and labor involved. It is not enough simply to grow crops, but they must be so produced as to yield a profit on the capital invested To succeed, he must be thoroughly acquainted with every detail of his occupation, and must strive to stop all leaks and prevent needless waste. At the same time, he must bear in mind that it is a good business principle to spend a dollar whenever he can see that it will come back to him with interest.

Agriculture is not merely a business but an art as well: the art of producing plants and animals that are useful to man. A real knowledge of farming necessitates a knowledge of the principles upon which the art of agriculture is founded; for an understanding of these principles is essential to an intelligent and rational practice. A few years since, "anyone could be a farmer." It was only necessary to sow and reap, for Nature dealt lavishly with man, and gave to him freely of the fertility she had been storing up for countless ages. A system of extravagant and unbusinesslike farming, however, has so impoverished the soil,



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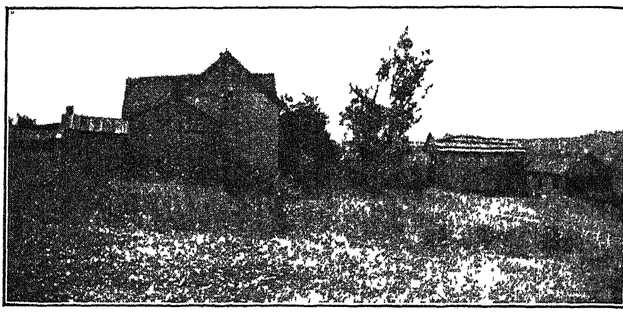
in some parts of our country, that many farms are already abandoned, having ceased to be profitable; and that too, in localities where the land once commanded high prices. This fact is the more lamentable, because the exhaustion of the soil might have been prevented by an intelligent foresight on the part of our earlier farmers. The farming of the future, therefore, must be done by men of broad training which should in-

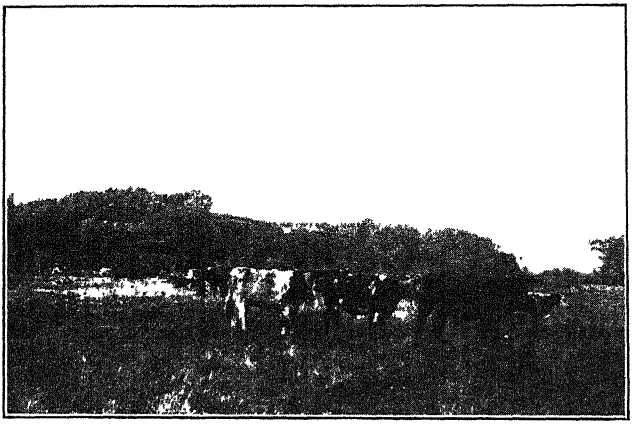


An abandoned farm. Many farms have been abandoned because the soil is said to be exhausted. This exhaustion of the soil might have been prevented and the soils in many cases can be restored to their original fertility

clude, among other things, some knowledge of such sciences as geology, chemistry, botany, zoology and physics. These sciences have done much to explain how the fertility of the land may be conserved, and it is the aim of this little book to present in a brief manner the latest views of agricultural investigators and farmers on this important subject The intention is to make the treatment of the subject thoroughly practical, and for this reason the minimum of theory and the maximum of demonstrated facts will be given, and

with the least possible use of technical language Before taking up the subject of manures and fertilizers it is desirable to devote a short time to the consideration of plant food in general, explaining what it is and its source of supply.

Plants of First Importance to the Farmer.—All agriculture depends upon the growth of plants, and



Plants are of first importance to agriculture, The production of animals and animal products is merely one way of marketing the crop

consequently the profit that accrues to the farmer depends primarily upon the value of the crops his farm produces. In some kinds of farming the profit comes from the sale of crops that are useful in providing food, fuel, or raiment for man, while in others the direct gain comes from the sale of animals or animal products. Even in the latter case the feeding crops that can be grown upon the farm determine its earning

power, for the sale of animal products is simply an indirect method of marketing the crops.

The profit from the farm is dependent not only upon the total crop produced but also, and to perhaps a still larger degree, upon the yield per acre. It stands to reason that if the crops now produced on two hundred acres could be grown upon one hundred, the returns would be greater, provided the labor and other expense involved were not materially increased, for in the latter case the interest on the money invested in one hundred acres of land would be clear gain On the other hand, it is apparent that nothing is gained by increased production per acre if the larger crop is obtained at a total expenditure in excess of that required for the smaller yield. As a matter of fact, our most successful farmers have demonstrated that the present average of crops can be doubled, and that at a cost per acre scarcely more than is now required for the half-crop. To accomplish this necessitates a broader knowledge of the food requirements of plants than is possessed by the majority of our farmers. This knowledge being fundamental, it seems strange that more efforts have not been made to acquire it by those vitally interested. Strange as it may seem, it is a fact that while he has reasonably clear ideas on feeds for animals, the average farmer has only very vague and often false notions on the subject of plant food and plant nutrition. A thorough understanding of these subjects on the part of our forerunners in agriculture would have rendered it unnecessary to deal with the matter considered in the next paragraph.

Exhaustion of the Soil.—It is a matter of common

experience that continued cropping results in a loss of fertility The experiences of the older sections of our country teach some lessons by which the newer parts may profit In the beginning the productiveness of the rich virgin soil seemed unlimited. For years large crops were produced with apparently no decrease in fertility. Sooner or later, however, the crops began to diminish in size, gradually, to be sure, but unceasingly, until at last the yield became so small that it no longer paid for the cost and labor of cultivation This state of affairs came about more rapidly if the same crop was grown continuously on the same field, as was often done with wheat The soil was now said to be exhausted, and in many cases the farms were abandoned. An exhausted soil in this sense means one that will no longer yield profitable returns, and not necessarily one that will produce no crop. As a matter of fact a soil can not become exhausted, if by exhaustion we mean total inability to produce a crop

At the experiment station at Rothamsted, England, barley grown continuously on the same plot for forty-three years without the use of fertilizers of any kind yielded in the forty-third year 10 bushels of dressed grain per acre; the average for the last eight years being 11¾ bushels. Wheat grown in the same way for fifty years produced in the fiftieth year 9¾ bushels of grain per acre; the average for the last eight years being 11½ bushels. In these cases the soil seems capable of keeping up the yield indefinitely, as the average for the last twenty years is practically the same as the average given above for the last eight years.

While these facts indicate that the soil can never be completely exhausted, it is exhausted for all practical purposes when the crop produced ceases to be profitable. The first question that naturally suggests itself is, Why does the productive power of the soil diminish?

The Plant Removes Something from the Soil.—It is evident that the virgin land must have contained large quantities of some substance or substances that were necessary to vigorous plant growth and that these materials were removed from the soil when the crop was harvested. It is not possible to explain the rapid decrease in fertility on any other basis; for it can not be ascribed to any changes in climatic conditions. The change in the physical condition of the soil has been suggested as a possible explanation for its decreased productive power, but even this is not an adequate explanation. It is apparent also, that plants vary in their power to extract these substances from the soil; for it is well known that a soil may be unfertile for one class of plants and still produce a luxuriant growth of another. To ascertain what these materials are that the plant removes from the soil, it is necessary to analyze the plant and then to determine the sources of the ingredients found there. For the purpose of this study the corn, or maize, plant is chosen, as it is perhaps the most important of all plants to the American farmer. Before presenting the analysis it is advisable to devote a moment to a few preliminary considerations.

Elements and Compounds.—Chemistry teaches that all matter is composed of simple substances called elements. Between 70 and 80 of them are known. They are called elements because they are the simplest sub-

stances known, and can not by any means yet discovered, be separated into simpler or different substances. Iron, gold, silver and sulphur are examples of elements. Two others, both gases (*i. e.* oxygen and nitrogen) make up the bulk of the air.

Most materials with which we are familiar are complex and are combinations of two or more elements. Such bodies are called compounds. While the number of elements is small there are many thousands of compounds. This is due to the fact that the same elements can combine in many different ways, each combination forming a different compound. Alcohol, sugar, starch, fats and acetic acid, for example, are substances very unlike in their properties and yet all consist of the three elements carbon, hydrogen and oxygen, but these elements are present in different proportions. Plants are composed of a large number of compounds, and an ideal analysis would first separate the plant into its compounds and then these compounds into the elements of which they are composed. Approximately such an analysis can be made.

Chemical Composition of the Corn Plant.—If a quantity of green corn is allowed to wilt in the sun it loses a large percentage of its weight by the evaporation of the water which it contains. If the remainder is now heated in an oven at 212° F. it again decreases in weight, but finally reaches a point where the weight does not change, because all the water is driven off. Water is composed of the two elements hydrogen and oxygen. What remains after expelling the water is called the dry matter of the plant. The dry matter burns on being ignited and a very small amount of

mineral matter remains, which is called ash The part that burned, and completely disappeared is known as organic matter. The organic matter is composed of four classes of compounds known as fat, crude fiber, carbohydrates and protein The first three of these compounds are made up of the elements carbon, oxygen and hydrogen; and the protein contains in addition to

Corn or maize is one of the most important crops for the American farmer. It removes large quantities of plant food from the soil, however. The analysis of the corn plant is given on page 11

these the element nitrogen. The ash contains the elements potassium, phosphorus, calcium, magnesium, iron, sulphur, chlorine, sodium and silicon. The following table shows the ingredients found in 1,000 pounds of the matured corn plant, *i. e.* when the plant is in condition to be cut for shocking.

From what has been said it will be seen that of the elements known only thirteen are found in plants; for what is true of the corn plant holds true of all other plants. It will be shown that of these thirteen, three are probably not necessary to plant growth, leaving only ten elements that are essential. The table shows

that three elements (*i. e.* hydrogen, oxygen and carbon) make up 98½ per cent of the entire composition of the plant, the remaining elements constituting only 1½ per cent.

COMPOSITION OF THE CORN PLANT

CORN PLANT 1,000 lbs.	Water 793	Hydrogen 88.1		
		Oxygen 704.9		
	Dry Matter 207	Organic Matter 195	Protein 18	Nitrogen 2.9
			Fat 5.	Carbon 90.5
			Fiber 50	Oxygen 88.9
			Carbohydrates 122	Hydrogen 12.7
		Ash 12	Chlorine 0.4	
			Potash 4.0	
			Phosphoric Acid 1.2	
			Lime 1.6	
			Magnesia 1.4	
			Iron Oxide 0.3	
			Sulphuric Acid 0.3	
			Soda 0.4	
			Silica 2.4	

(NOTE.—All of the elements mentioned above as occurring in the ash, with the exception of chlorine, are combined with oxygen. In the table the names under "ash" represent these combinations, *i. e.* potash is composed of potassium and oxygen; phosphoric acid is phosphorus and oxygen; lime is calcium and oxygen, etc.)

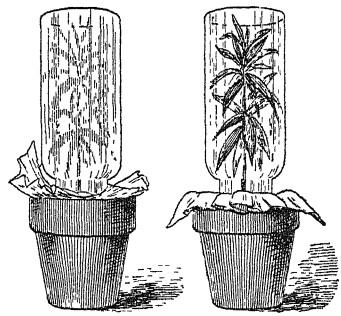
CHAPTER II

ATMOSPHERE AS A SOURCE OF PLANT FOOD

Importance of Water to the Plant.—One of the most striking points brought out by the chemical analysis is the large proportion of water that enters into the composition of the plant. A reference to the table shows that nearly 800 of the 1,000 pounds of the matured corn plant consist of water in a form that can be driven off at a heat not above the boiling point. In the organic matter is found 12.7 pounds of hydrogen and 88.9 pounds of oxygen which practically all came originally from water, making a total of nearly 900 pounds derived from this source. These figures represent but a small part of the water actually required by the crop. Water is being continually given off into the air by the plant-leaves This exhaled, or "transpired," water is in the form of a vapor and is invisible, but that it actually exists can be proved by a simple experiment.

Invert a wide mouthed bottle or fruit jar over a small plant, and after a short time the inner surface of the bottle will be found to be covered with moisture. The earth around the plant should first be covered with a piece of oil cloth or oiled paper to make sure that the water does not come from the soil. If the underside of a leaf is examined with a magnifying glass or microscope it will be found that the surface is not entire,

but is perforated by numerous small openings. These openings are called "stomata" (little mouths), and it is through these that the water is exhaled. This power of transpiration continues during the life of the plant, the water being obtained from the ground through the roots. Very large quantities of water are used in this way.



Experiment to show that water is given off from the leaves of plants. The bottle on the left has been over the plant for some time and is cloudy from the moisture which has collected on the inside. The one on the right has just been placed over the plant and is transparent.
(Drawn from photograph)

Amount of Water Required by Crops. — European experiments have shown that approximately 300 pounds of water passes through the plant for each pound of dry matter produced, so that 1,000 pounds of corn uses at least 30 tons of water during its growing period. As this quantity of corn can be raised on one-thirtieth of an acre, it follows that to mature an acre of corn the crop must be supplied with 900 tons of water, or an amount that would make a layer over the acre about 8 inches deep.

This again takes no account of the quantity of water lost from the land by percolation or drainage. It has been estimated that this amount is at least equal to that used by vegetation, so that one acre of corn probably requires a precipitation of at least 1,800 tons of

water. These statements show clearly the necessity of carefully conserving the moisture of the soil, a point that can not be too strongly emphasized.

King found in investigations made at Wisconsin that the amount of water used by the crop was from 300 to 500 times the weight of the dry matter. His results are summarized in the following table.

AVERAGE AMOUNT OF WATER USED TO PRODUCE ONE TON OF DRY MATTER

Crop grown	*Tons of water for one ton dry matter*
Barley	461.1
Oats	503 9
Corn	270.9
Clover	576.6
Peas	477.2
Potatoes	385.1

From this and other data he calculated the minimum amount of available water necessary to produce the various yields of the more common grain crops. These interesting figures are given below.

LEAST AMOUNT OF WATER PER ACRE REQUIRED TO PRODUCE DIFFERENT YIELDS OF GRAIN

Yield per acre	*Acre Inches of Water Required*			
	Wheat	*Barley*	*Oats*	*Corn*
15	4.5	3.24	2.35	2.52
20	6 0	4.28	3.14	3.36
30	9.0	6.42	5 7	5.04
40	12.0	8 56	6.27	6.72
50	15.0	10.70	7.84	8.40
60	18.0	12.84	9.40	10.08

Functions of Water.—Water is important to the plant in several different ways. It is first of all the most essential plant food, in the sense that it composes about 80 per cent of the mature crop. It also supplies the hydrogen and oxygen found in the dry matter, which amounts to 10 per cent more, making a total of 90 per cent of the weight of the plant which is derived directly from the water.

Water is necessary to dissolve the plant food in the ground, and enable it to enter the plant, as will be noted later. It is needed to give stiffness or rigidity to the more succulent parts of the plant This fact is shown by the drooping or wilting of plants during the hot hours of the day when the water is not furnished by the roots with sufficient rapidity to replace the loss by evaporation from the leaves. It is probable that water performs an important function in controlling the temperature of the plant. The chemical processes in the plant cells produce heat, and the excess of heat is removed by transpiration of water through the leaves, just as it is removed from the human body by the transpiration (perspiration so-called) through the skin. Water is also necessary for the movement of food within the plant. The food materials absorbed by the roots, and that manufactured by the leaves can be transported to the different parts of the plant where they are needed only when in solution in water.

Of such consequence to vegetation is the water supply that some investigators claim that the question of fertility is wholly one of having present in the ground the proper amount of moisture, and that it is independent of the chemical composition of the soil, except as

this composition affects its power to furnish the plant with water. This view is undoubtedly extreme, and is not generally accepted. There is no doubt, however, that the proper condition of moisture is the most important single factor in determining the fertility of the land, and that more soils fail to produce good crops for lack of it than for any other cause. It seldom happens that the water supply is sufficient to grow the maximum crop of which the soil is capable, as is demonstrated by the fact that a large increase in yield can be obtained by irrigation even in sections of very heavy precipitation. While the amount of water that falls on the land can not be controlled, much can be done to save the water so as to tide over the periods of scanty rainfall; a fact that will be emphasized throughout this book. Too much stress can not be laid upon the importance to the plant of an adequate supply of water in the soil, and the knowledge that certain methods increase the amount of moisture available to the crop should be sufficient reason for their adoption. The reader is asked to carry this thought with him as he reads the following pages.

Part of the Oxygen from the Air.—A small quantity of the oxygen in the plant probably comes from the air. One-fifth of the volume of the air is oxygen, and the plant uses this to some extent. Plants breathe in much the same manner that animals do, for all cells must have a supply of oxygen in order to live. The oxygen of the air combines with the materials in the cells one of the results being the production of heat, just as the oxidation taking place in the animal body produces heat. That heat is evolved by the living

vegetable cell can easily be proved experimentally by confining the plant in such a way as to prevent radiation. The rapid heating of silage in the silo is doubtless due to the breathing process of the cell, the heat in this case being unable to escape.

Carbon in Plants Derived from the Air.—Nearly one-half of the dry matter in the plant consists of the element carbon, all of which is derived from the carbonic acid gas which is present in the atmosphere. Carbonic acid is the colorless gas which is formed when a piece of coal or charcoal is burned, and is a compound containing the two elements carbon and oxygen. Charcoal is a good example of nearly pure carbon. Carbonic acid gas is found everywhere in the atmosphere, although present in very small quantities, constituting only four one-hundredths of one per cent of the volume of the air, or about four parts in 10,000. It seems strange to think that so large a proportion of the solid material of the plant should be formed from this gas, but it is well known that green plants have the power to decompose this gas, retaining the carbon and setting free the oxygen. This process is known as the "fixation (sometimes assimilation) of carbon," and takes place chiefly in the leaves. The power to fix carbon is dependent in some way on the presence of the green coloring matter (chlorophyll), so that it is only those plants having green leaves that can use the carbonic acid. Such plants as mushrooms and other fungi, for instance, can not obtain their carbon in this manner but must procure it through the decomposition of organic matter, or in other words, must have their food previously prepared for them. Green

plants, on the other hand, can manufacture their own food from the inorganic materials of the soil and atmosphere.

Sunlight Necessary to Carbon Fixation.—The decomposition of carbonic acid by the plant, and the assimilation of the carbon take place only during the daytime. A certain amount of energy is necessary to break apart the carbon and oxygen of carbonic acid, and this energy is furnished by the sunlight. The stronger the light the faster the fixation of carbon. This explains the commonly observed fact that most plants grow more vigorously in full sunlight than in shade or diffused light The plant has not the power to use carbonic acid in the absence of light, so that this process ceases during the night. It is well known that seeds will germinate in the dark, and produce a feeble spindling growth of pale foliage, but that the plants so produced soon cease to develop. Such plants grow until they exhaust the food stored in the seed, but have no power to use the food in the air and soil, and analysis shows that the plant contains less dry matter than was present in the seed. In the presence of light, however, the plant absorbs the carbonic acid of the air by means of its leaves, and causes the carbon to combine with the water and mineral matter taken in through its roots to form carbohydrates, proteids and the other complex compounds of which the plant is composed.

Carbonic Acid the Sole Source of Carbon.—It has been thoroughly demonstrated that the green plants derive their carbon solely from the carbonic acid of the atmosphere, and are not dependent in any way

upon the carbonaceous matter in the soil. In fact, that they are incapable of using carbon except in the form of carbonic acid gas. The quantity of carbonic acid in the air seems so insignificant that it might be feared that the supply might some day be exhausted. The bulk of the atmosphere is so enormous, however, that the total amount of carbonic acid is very large. Johnson calculated that the atmosphere when taken to its entire height contains not less than 3,400,000,000,000 tons of carbonic acid. This amounts to about 28 tons over every acre of the earth's surface, and as only one-fourth of the earth's surface is land he estimated that the carbonic acid in the air is sufficient, without renewal, for a hundred years of growth. As a matter of fact, the supply of this gas is being constantly renewed, and at such a rate that the proportion found in the air remains about constant. When wood or coal or any other substance containing carbon is burned, carbonic acid is formed and passes into the atmosphere. This gas is produced during all kinds of decay and fermentation. Animals live directly or indirectly on plants, and breathe out the carbon they consume in the form of carbonic acid gas. It will thus be seen that the carbon is continually in circulation, being combined by the plant into complex compounds only to be broken down, and returned again to the air through these various agencies. In all probability that now present in the air has been many times built up into organic matter, only to be again set free by decomposition.

Numerous experiments have proved that the supply of carbon in the air is ample for the largest crops. To be sure, in certain pot experiments a larger yield was

obtained by increasing the carbonic acid in the air, but under field conditions the yield is limited by other factors, and never by the supply of carbon.

Carbon Costs the Farmer Nothing.—The point of practical importance brought out by this study of the fixation of carbon is that the carbon is furnished free of cost. In other words the carbon compounds produced in the crop result in no impoverishment of the soil. Hence, there is no need of supplying strictly carbonaceous manure to the field, as the crop does not use the carbon in the soil. It will be shown later that such manures may be indirectly beneficial to the plant, however.

CHAPTER III

NITROGEN AS A PLANT FOOD

Nitrogen the Most Costly Plant Food.—A reference to the table given in Chapter I shows that only about $1\frac{1}{2}$ per cent of the dry matter of the corn plant consists of nitrogen. Some plants contain more nitrogen than this, but the amount rarely equals 3 per cent of the dry matter, or six-tenths of one per cent of the green plant. In spite of the small quantity of nitrogen in the crop it is the most important of all plant foods from the practical point of view. In fact the solution of the problem of the maintenance of fertility depends upon an economical method of conserving and renewing the nitrogen supply of the soil. This does not imply that nitrogen is more necessary to vegetation than are the other constituents, but that it is the most expensive element to be furnished by means of fertilizers, and is also, unfortunately, the element most easily lost and wasted.

The Nitrogen of Most Plants Comes from the Soil.—Most of the crops raised by the farmer are entirely dependent upon the soil for their supply of nitrogen. The greater part of the nitrogen present in the soil is locked up in the insoluble organic matter, and in this form is not available to plants. Some of the nitrogen exists in simple compounds called nitrates, which consist of nitric acid combined with one of the mineral elements of the soil. The majority of farm crops can

use only that part of the nitrogen in the soil that is present as nitrates, so that so far as the nitrogen is concerned, the fertility of the land depends upon its nitrate content. The nitrate present in the soil at any one time is exceedingly small, but under proper conditions the supply may be renewed with sufficient rapidity to meet the needs of the plant.

Source of the Nitrogen of the Soil.—A small part of the nitrogen in the soil is derived directly from the atmosphere. Minute traces of ammonia (a compound of nitrogen and hydrogen) are always found in air, and during electrical storms small quantities of the nitrogen and oxygen in the atmosphere are combined to form nitric acid. These substances are dissolved in the rain water during showers and are carried into the soil The quantity received by the soil from this source is very small, amounting only to from 3 to 8 pounds an acre a year, the maximum amount being less than one-tenth of that required by a crop of corn. Nearly all of the nitrogen in the soil is present in the more or less decayed organic matter left behind by the plants that it has previously produced. Plants build up the nitrogen into complex protein compounds, and, under ordinary conditions, when they die these substances in connection with the other constituents of the plant become a part of the soil. As long as the nitrogen remains in this form it is of no value to the new generation of plants, for the organic matter must first be decomposed, and the nitrogen changed into the form of nitrates.

Nitrification.—The soil must not be regarded as an inert mass of mineral matter and refuse of former

plant growth. It is, in fact, an immense laboratory in which millions of tiny workmen are bringing about marvelous chemical changes. The principal factors concerned in these transformations are bacteria, of which, it is estimated, there are present in the neighborhood of one hundred fifty millions in each ounce of surface soil Some of these bacteria cause the fermentations and decay that return the carbonic acid to the air. Others, and these are of particular interest here, bring about the decomposition of the nitrogenous organic matter with the ultimate production of nitrates.

The transformation of organic nitrogen into nitrates undoubtedly results from the action of more than one species of bacteria, and takes place in three or more different steps The organisms necessary to produce these changes are ordinarily present in all soils. Nitrification takes place only when the temperature is more than 5° above freezing, and becomes more rapid with rise of temperature. Hence, it ceases during the winter months, and is most vigorous during the hot months of midsummer. The nitrifying bacteria can not live without a sufficient supply of oxygen, and, for this reason, stirring up the soil, and thus introducing air, increases the rate of nitrification. Nor can these bacteria thrive in a soil that is acid, so that the presence of carbonate of lime, or some other substance that will neutralize any acid produced in the soil, is essential to nitrification. All of these points will be discussed in greater detail later; for the present it is sufficient to emphasize the importance of the process of nitrification to the growing crop. So vital indeed, is the subject that successful agriculture may be said to de-

pend largely upon providing proper conditions for rapid nitrification.

Denitrification.—While the nitrifying bacteria may be said to be the farmer's friends, there are, unfortunately, in the soil other organisms which produce evil results. One class of these, known as denitrifying bacteria, decompose the nitrates, and perhaps some other nitrogenous compounds, with the final result that the nitrogen is set free and returned to the air in its elemental condition. This process of course, robs the soil of a part of its nitrogen, and is especially unfortunate because it removes the part that was most readily available to the crop. The conditions that are detrimental to nitrification (*i. e.* lack of oxygen, presence of acidity, etc) are those that favor denitrification, so that the farmer in producing proper conditions for the former desirable process is at the same time preventing the injurious denitrification.

Can Plants Use Free Nitrogen of the Air?—About four-fifths of the volume of the air consists of the element nitrogen, so that if this were generally available to plants there could be no such thing as "nitrogen starvation." Perhaps no question in the realm of agricultural chemistry, or plant physiology, has received so much attention as the relation of the plant to the nitrogen of the atmosphere; but many points still remain to be investigated. The question heading this paragraph can best be answered by a very brief historical review of the subject. At one time it was generally believed that the air was the sole source of the nitrogen supply for the plant. The first important experiments that indicated the contrary were those in which Bous-

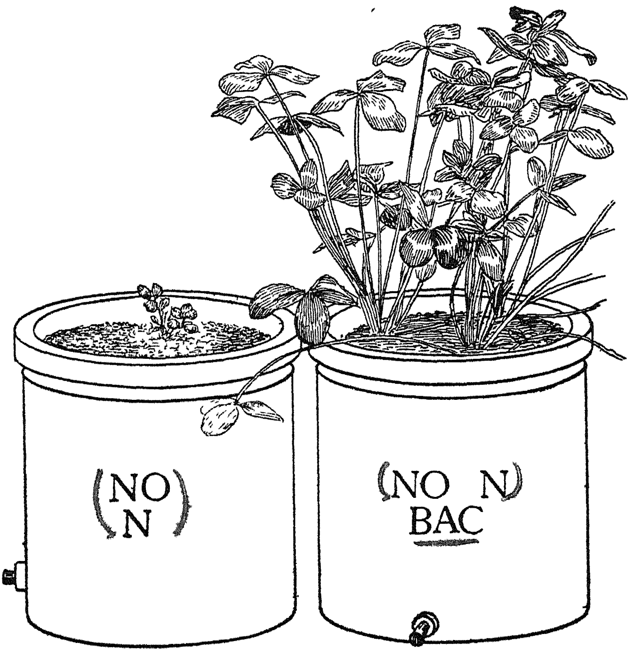
singault grew plants in sterile soil free from nitrogen, the plants being so protected that they came in contact with no nitrogen save that of the air. The plants grew for a short time only, and upon analysis showed that they contained no more nitrogen than was present in the seed. Similar experiments conducted by Ville gave contrary results. To decide the matter, a great number of painstaking experiments were carried out at Rothamsted, England, all of which confirmed the results obtained by Boussingault, and the question was considered settled by most experimenters. About the same time field tests were conducted at Rothamsted which indicated that when clover and other leguminous plants were grown, there was an actual gain of nitrogen in the soil, in addition to that removed by the vegetation, while the growth of cereals resulted in a loss of nitrogen. Other experimenters also arrived at the conclusion that clover has the power of procuring nitrogen from some unknown source. Farmers had known for some time that wheat grown after clover does as well as when manured with a nitrogenous fertilizer. Some writers tried to explain this fact by assuming that the clover roots bring up the nitrogen from the deep subsoil and leave it near the surface, but the explanation was never satisfactory.

The conditions under which the pot tests were conducted were not normal, as the plants were grown in prepared soils that had been heated to kill any bacteria they might contain. It occurred to Atwater that plants grown under natural conditions might use free nitrogen even though they did not under the conditions of these experiments. He, therefore, grew plants in pots in the

open, analyzing the soil before the experiment and the soil plus the plant at the end of the growing season, correcting for the nitrogen carried down in the rain water. He found that while in most cases there was no gain of nitrogen, in some cases there was a decided increase. Those plants which produced a gain in nitrogen invariably belong to the same family as the pea, bean, clover, etc., or in other words to the so-called "legumes" or "leguminous plants." It remained for Hellriegel to explain this phenomenon. He repeated the experiments of Boussingault with this variation that to the soil in some of the pots he added a small quantity of water leached from a natural soil so as to introduce any bacteria that might exist naturally in the earth. He found that in the perfectly sterile soil there was no gain in nitrogen by any of the plants, but that in the pots to which the soil leachings had been added the legumes grew vigorously, while the cereals produced only feeble and short-lived plants. Upon examination of those legumes which made marked growth he found that they all had numbers of small nodules or tubercles on their roots, and these nodules on inspection were found to contain innumerable bacteria.

Further tests have demonstrated that when leguminous plants are grown in soils containing the proper bacteria, they can indirectly make use of free nitrogen, and are practically independent of the nitrogen in the soil. This property is not a function of the legume itself, but of the bacteria that produce the nodules, and in the absence of these organisms the legumes are quite as dependent upon the supply of nitrates as are

the other orders of plants. It may be further said that so long as the leguminous plant can procure in the form of the nitrates all the nitrogen it needs the nodules



Showing the power of clover to obtain nitrogen by means of the bacteria in the root-nodules. Both pots received all the elements of plant food except nitrogen The pot on the right was inoculated with the proper bacteria, while that on the left was not

will not be formed. For that reason, in a soil rich in nitrogen the root tubercles may not be found on the legumes, even when the proper bacteria are present. Yet for all practical purposes it may be taken for granted that clover, peas, beans, alfalfa and other

legumes derive the bulk of their nitrogen from the air, and that in growing them the farmer is not decreasing the nitrogen content of the soil, but may actually be adding thereto.

Inoculation of the Soil.—Experience has shown that all soils do not contain the bacteria necessary to

Root tubercles on soy beans. The left inoculated and the other uninoculated. Tubercles appear only when the proper bacteria are present in the soil

the fixation of free nitrogen by legumes. They may be introduced into a field by sowing with the seed a small quantity of soil from a field in which the legume has been successfully grown. This has been done so often as to leave no doubt of its practicability. Late investigations have shown that the same species of bacteria will not do for all legumes; so that a soil, for instance, may grow clover to perfection, when soy beans or alfalfa will not thrive on it at all. This fact explains many of the disappointments experienced by farmers in the trials of some of the more recently

Effect of inoculation on yield. The plant on the left came from a plot where all the plants had nodules on roots; the other from a plot where practically none of the plants had nodules The yield was in the ratio of the size of the plants shown in the illustration

introduced leguminous crops. While inoculation of the soil is of undoubted use in some cases, there is danger of overestimating its value. It must not be regarded as a panacea for all the ills of the soil. Inoculating a soil simply introduces the nodule forming bacteria, and if the failure of the leguminous crop was due alone to absence of these bacteria the results will be beneficial It will in no wise overcome failure due to bad seed, improper preparation of the ground, adverse weather conditions, acidity of the soil, etc, and the farmer should assure himself that the soil conditions are as favorable as possible before he attempts inoculation

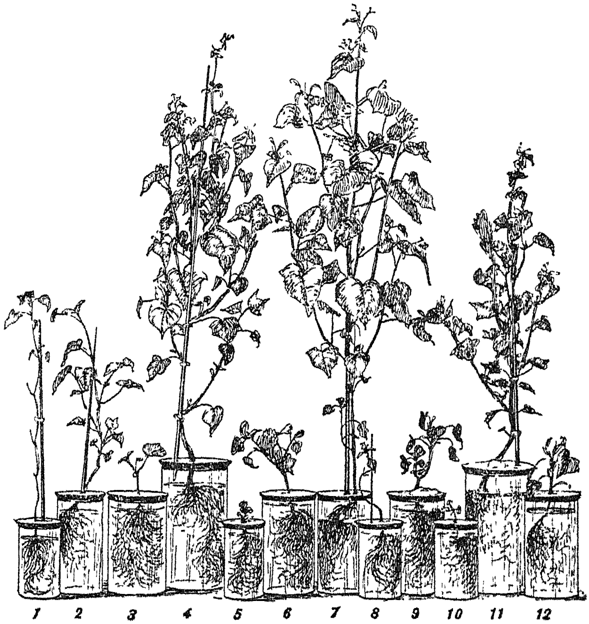
Other Ways in which Nitrogen is Fixed.—Within the last few years a number of bacteria have been discovered in the soil which have the power, when cultivated in the laboratory, of using free nitrogen, and which do not grow in connection with the higher plants. These bacteria are found in most soils, and may be an important factor in maintaining the supply of nitrogen in the soil. At the present time it is impossible to say whether the nitrogen added to the soil in this way is of any considerable moment.

CHAPTER IV

SOIL AS A SOURCE OF PLANT FOOD

Mineral Constituents of the Plant.—There still remains to be considered the mineral matter found in the ash, or that material which remains when the organic part of the plant is destroyed by burning and which corresponds exactly to the ashes left in the stove after burning wood. The substances found in the ash are all derived from the soil. It has not always been thought that they were necessary to plant growth. The earlier writers on agriculture considered only the organic matter of the soil and certain constituents of the atmosphere as of any importance to the plant. These writers thought the presence of mineral matter merely accidental, and due to the fact that the plant took it because it was dissolved in the necessary soil water, and had no way of rejecting, or removing it. Later writers, however, preeminent among whom was Liebig, proved that the ash ingredients are necessary to the plant. A very simple experiment was sufficient to show that at least some of the mineral matter was essential to plant growth Seeds were planted in quartz-sand in pots, to one of which nitrogen compounds alone were supplied, and to the other, nitrogen and a small amount of plant ash. The plants in the pot which received the ash grew to maturity, while those in the other pot made only a feeble, short lived growth.

Essential and Non-Essential Elements.—The experiment just described proves that there is something in the ash that is required by the plant, but does not show whether only a part or all of the ingredients are



Experiment to show the essential elements of plant food. Numbers 4, 7, and 11 received all the elements of plant food while one element was withheld in each of the other tests

essential. This question naturally interested a number of investigators, and soon a mass of evidence was at hand. In order to determine which elements are essential, plants were grown, either in specially prepared sand or by the "water-culture method," in such

a way that they were supplied with all the elements occurring in plants, with the exception of the one element under investigation. If the plant grew to maturity the element which was missing was deemed non-essential. If, on the other hand, the plant failed to develop, that particular element was considered to be essential.

The numerous experiments of this kind which have been carried on show that of the ash constituents potash, lime, phosphoric acid, magnesia, iron and sulphuric acid are absolutely essential to plant growth. Toward soda, chlorine and silica plants seem to be indifferent, as they can grow to maturity in the absence of these substances. For this reason it is generally conceded that only ten of the thirteen elements found in the plant are essential to growth, soda, chlorine and silica being thought non-essential. Accepting this view and referring again to the table on page 11 it is seen that 1,000 pounds of corn plant contain only 9 pounds of essential mineral matter or about 0.9 per cent. Attention is called to the fact that these experiments extended over only one generation, and that it is possible that an attempt to grow the crop through successive generations in a soil devoid of soda, chlorine or silica might show different results.

One Element can not be Substituted for Another.—The experiments mentioned above have shown, not only that certain chemical elements are necessary to plant growth, but also, that it is not possible to replace these essential elements even by others which are similar in chemical properties. In the chemical laboratory, for example, it is found that soda and potash are very

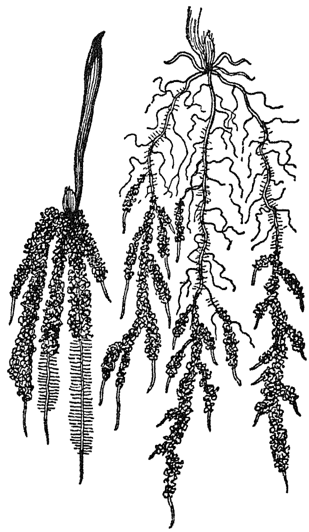
much alike in their action, and one may be used in place of the other in many operations. It would be a good thing for agriculture if soda could be substituted for potash as a plant food, as compounds of sodium are very inexpensive compared with potash compounds.

Spinach: *a* full ration soda; *b* full ration potash
One element of plant food cannot take the place of another in promoting plant growth. The pile on the right shows spinach grown with complete fertilizer. The pile on the left received the same fertilizer with potash replaced by soda

This point has been thoroughly investigated, and it has been demonstrated that soda can not take the place of potash as a fertilizer. As a definite amount of each of these elements is required for a certain yield, and none of the elements can be replaced by another, it seems to follow that the crop produced will be limited by the quantity of the essential element present in least proportion, compared with the requirements of the crop. In other words, if a field of corn can obtain

potash sufficient for only half an average crop, no more than this can be produced no matter how much of the other forms of plant food is present.

How the Mineral Matter Enters the Plant.—It seems evident that the mineral matter must be taken up in some way by the roots. All are familiar with the fact that the soil is not a solid mass but consists of small particles, or "grains," with air spaces between, these spaces in the surface foot amounting to fully half the bulk of the soil. These grains vary in size according to the character of the soil, being very fine in clay, and comparatively coarse in sandy soils. The roots of the plant push down between these soil grains, branching more or less, and spreading throughout the soil. Surrounding the growing tip of the root are great numbers of fine root hairs that work their way in between and around the small soil grains, adhering closely to them and covering an immense amount of surface. It is on these root hairs that the plant is dependent for the absorption of its water and mineral food.



Root-hairs on wheat when very young and four weeks later. All the water and food from the soil enter the plant through the root-hairs. Note how closely the root-hairs adhere to the soil particles. (After Sachs)

It was once thought that plants actually took in the very small solid particles of soil, and that the purpose of cultivation is to render the particles minute enough for the plant to absorb. It is now known that no food can enter the plant unless it is in solution Each soil grain is surrounded by a film of water, and this water contains dissolved in it tiny quantities of the mineral ingredients of the soil, including nitrogen in the form of nitrates. The root hairs absorb the moisture as it is required by the plant, and with it such mineral matter as it needs. Both water and the dissolved matter enter the plant by the process known as osmosis. Each element is absorbed independently of the others, and the plant can in a way refuse to absorb more of any one ingredient when it has all that is needed for its growth. This "selective power" of the plant (if it may be so called) is shown by the fact that two different kinds of crops grown on the same soil may differ greatly in their composition. The ratio between the chemical elements found in them may be entirely different in the two crops and may be, in a great measure, independent of the ratio existing between these elements in the soil water.

Soil Solutions Very Dilute.—The amount of mineral matter in the soil water is very minute. In the second chapter attention was called to the fact that at least 300 pounds of water must pass through the plant to produce one pound of dry matter. The fact that the soil water contains mere traces of plant food probably accounts, in some measure, for the immense quantity of water used by the plant, as it must absorb this water to obtain the food it requires. The plant is

not entirely dependent upon the mineral matter actually dissolved in the soil water for its supply of food. The roots have the power of secreting an acid substance that has a solvent action on that part of the soil which is insoluble in pure water. This is shown by the root tracings often seen on pieces of limestone in the soil. It may be shown by growing a plant in a small quantity of soil placed on a piece of marble. If the marble is examined after a time the outlines of the roots can be seen distinctly where the acid substance has cut into its surface. How great a factor in obtaining food this property of the plant is can not be stated at present on account of our limited knowledge of the subject.

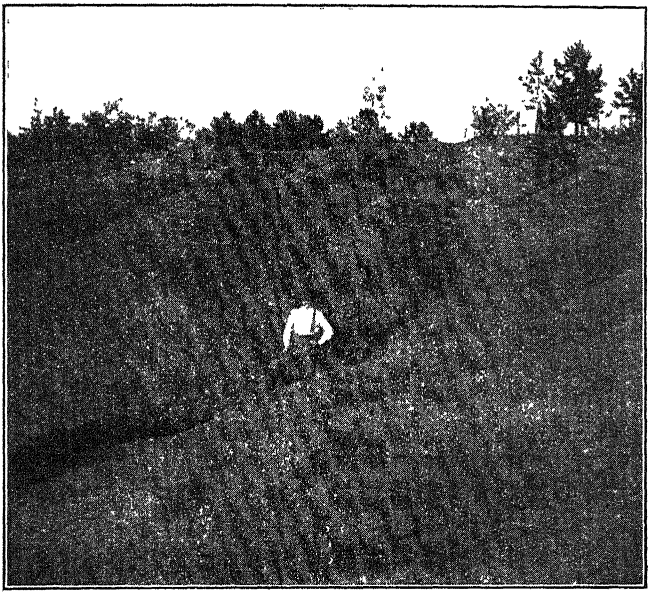
Function of the Different Food Elements.—Now that the source of the different elements required by the plant has been briefly discussed, it is desirable to have explained the special function in the vital processes of the plant performed by each of these substances. Unfortunately but little is known in regard to this subject, for up to the present time it has almost defied investigation. Carbon, oxygen and hydrogen are found in all the organic compounds of the plant and form about 98½ per cent of the green corn crop. Nitrogen is a constituent of proteids and is necessary to their formation. Sulphur is found in some of the proteids but its special function is not known. Phosphoric acid is supposed to be in some way connected with the transportation of the proteids from one part of the plant to another. Potash is thought to be necessary to the conversion of starch into sugar and, consequently, to its removal from the leaves to other parts

of the plant. As starch itself is insoluble, it must be converted into sugar before it can be transported. Iron is necessary to the production of chlorophyll. A plant grown in a soil devoid of iron contains no chlorophyll and, therefore, does not possess the power of fixing carbonic acid gas and manufacturing starch Lime probably performs a number of functions, one of which is to neutralize the poisonous oxalic acid formed in the plant and render it harmless by producing the insoluble calcium oxalate. Of the part played by the other elements practically nothing is known.

Other Ways in Which Plant Food is Lost.—In the first chapter it was suggested that the decrease in fertility of a soil might be due to the fact that the crop removes from it something that is essential to plant growth, and the following paragraphs have been devoted to determining what these essential elements are. Before proceeding to apply the knowledge thus gained, brief mention will be made of two or three ways in which plant food may be lost, other than by removal of the crop:

First, by leaching of the soil, or removal of plant food in the drainage water. For practical purposes nitrogen may be said to be the only element lost in this way. As the nitrogen removed by leaching is all in the form of nitrates, any loss from this cause is extremely unfortunate. The soil has the power of fixing most of the mineral elements, so that only traces of them are lost in the drainage water. The fact that certain mineral fertilizers are fixed by the soil can be shown by a simple experiment. A tall cylinder is filled with soil and to it is added a quantity of water in which are dis-

solved compounds containing nitrate nitrogen, phosphoric acid and potash. If the water that leaches through this soil is analyzed, it is found that the potash



It is a dangerous practice to allow soils to remain bare and exposed to washing rains. Thousands of acres of good lands have been destroyed in this country in the manner shown in this illustration

and phosphoric acid have been removed by the soil, but that the nitrogen all remains in the leachings.

Second, by surface washing. In hilly countries this may be a very important factor. As the soil is removed bodily from the surface of the field, it follows that the loss in this case falls on all the food elements. It affects nitrogen and phosphoric acid more than the

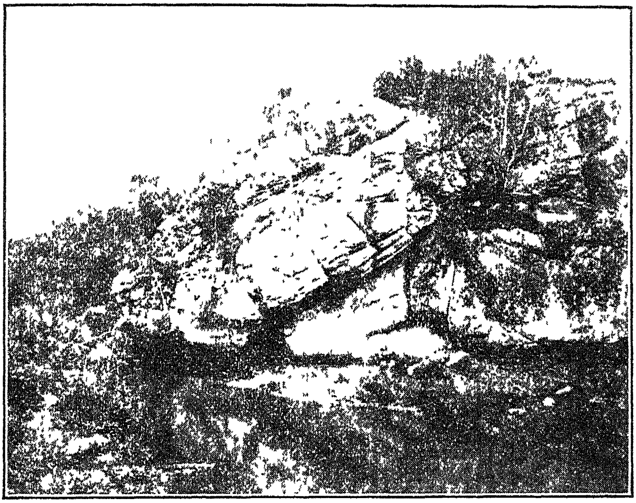
other ingredients. Most of the nitrogen is in the organic matter which is near the surface, and, being lighter than the rest of the soil, is more easily washed away. In most soils the first foot contains a larger proportion of phosphoric acid than the subsoil.

Third, by denitrification. This has been referred to in a previous chapter and may be of great moment in a soil that is not properly managed. The conditions that are desirable in the soil are such as best prevent denitrification, so that the farmer who understands his business need not fear this source of loss.

It is evident that in all these cases the heaviest loss falls on the nitrogen, the most expensive element to supply, and emphasizes a former statement, that the maintenance of fertility is largely a question of an adequate supply of nitrogen.

A Small Part of the Plant Food is Derived from the Soil.—Attention is again called to the fact that the atmosphere is the original source of 98½ per cent of the materials found in the green plant; the carbohydrates, fats and fiber being composed of elements supplied in the form of water and carbonic acid gas. These substances are furnished free of cost in humid climates, the supply being practically beyond control, and their use by the plant results in no impoverishment of the land. The subject of practical importance to the farmer is the supply of the other 1½ per cent of the plant, consisting of nitrogen and the ash elements which are derived directly from the solid particles of the soil. It has been shown that seven of these elements are essential to plant growth. Experience has proved that only three of these elements (*i. e.* nitrogen,

phosphoric acid and potash) are likely to become exhausted, or, in other words, that nothing is gained by adding to the soil any of the other elements of plant food. This is due to the fact that the plant uses nitrogen, phosphoric acid and potash in rather larger quan-



What immense quantities of plant food this hill must contain, but who can tell how much of it is available to plants?

tities than the other elements, and that they exist in smaller quantities in the ground, and not because they are any more essential to vegetation. Occasionally soils are found that are actually deficient in lime, but in most cases lime is present in sufficient abundance for the growth of the plant. In this study of the effect of the removal of the crop upon the amount of plant food in the soil, then, it will simplify matters to confine

attention to the three substances nitrogen, phosphoric acid and potash, assuming that all other elements are present in the earth in abundance.

Amount of Fertility Removed by Crops.—The different crops vary greatly in the amount of the three valuable fertilizing ingredients which they contain. The following table gives the amount of nitrogen, phosphoric acid and potash in 1,000 pounds of some of the important crops, the different materials being selected to show something of the range of composition.

AMOUNT OF FERTILIZING INGREDIENTS IN CROPS

1,000 POUNDS OF	*Pounds of Nitrogen*	*Pounds of Phosphoric Acid*	*Pounds of Potash*
Corn fodder, with ears	17.6	5.4	8.9
Corn, ears only	14.1	5.7	4.7
Timothy hay	12.6	5.3	9.9
Wheat, grain	20.2	8.7	5.5
Oats, grain	16.5	6.9	4.8
Clover hay	21.2	5.5	18.7
Tobacco	24.5	6.6	40.9
Cabbage	2.4	1.4	5.8
Potatoes	5.7	1.2	3.8

Notice the great difference in the amount of fertilizing materials removed in 1,000 pounds of the various crops as shown in the table, especially under nitrogen and potash. For the purpose of this discussion the

percentage of fertilizing ingredients in the crop is not of so much importance as the total amount removed by it from each acre of ground. The next table gives the amounts of nitrogen, phosphoric acid and potash removed from an acre by a few of the common crops. (*Adapted from Van Slyke.*)

AMOUNT OF FERTILITY REMOVED FROM AN ACRE

KIND OF CROP	YIELD	*Pounds of Nitrogen*	*Pounds of Phosphoric Acid*	*Pounds of Potash*
Corn, grain only	45 bus.	63	24	26
Clover hay	2 tons	82	18	88
Cabbage	15 "	100	35	135
Barley	30 bus.	56	17	51
Wheat	15 "	31	10	13
Wheat	30 "	62	20	26
Oats	45 "	45	16	37
Tobacco	1600 lbs	76	16	200
Timothy hay	1½ tons	38	15	45

An interesting point brought out by the table is the great difference in the total amount of plant food removed from an acre by the various crops. It is readily seen that certain crops must exhaust the fertility of the soil more rapidly than others, and common experience shows that the plants which remove large quantities of the essential plant foods are those that most quickly render the land infertile.

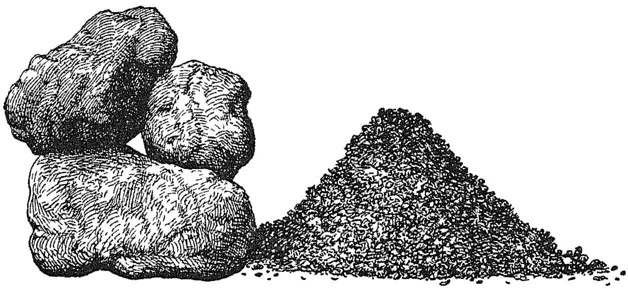
Amount of Plant Food in the Soil.—The bearing of the above facts upon the question of the maintenance of fertility can not be fully shown, unless the amount of plant food existing in the soil is determined. Large numbers of analyses of soils have been made and, as might be expected, these analyses show great variations in the composition of the soils. The following table gives the amount of nitrogen, phosphoric acid and potash in the first foot of typical sandy loam, clay loam and clay soils.

AMOUNT OF PLANT FOOD PER ACRE IN THE SURFACE FOOT

KIND OF SOIL	*Nitrogen, Lbs. per acre*	*Phosphoric Acid, Lbs. per acre*	*Potash, Lbs. per acre*
Sandy loam	3,736	7,326	28,669
Clay loam	4,789	4,935	44,827
Clay	3 250	5,600	12,600

The large amount of plant food present in the soil is surprising, in view of the fact that it is so hard to maintain a satisfactory yield of crops. Comparing the last two tables it is seen that the analysis of the clay loam soil shows the presence of sufficient nitrogen for 77 crops of wheat yielding 30 bushels to the acre; enough phosphoric acid for 246; and potash to supply 1,724 such crops. The second and third foot contain nearly as much phosphoric acid and potash as the surface foot, so that so far as these two substances are

concerned the supply seems almost inexhaustible. Although the chemical analyses of many of the soils upon which wheat has been grown show fully as large amounts of plant food as the clay loam under discussion, experience has demonstrated that long before the smallest number of crops mentioned above (*i. e.*



The physical condition of the soil is as important as its chemical composition. The lumpy soil contains as much plant food as the friable soil, but the plant roots cannot penetrate the hard lumps to obtain it

77) have been produced the yield will have so decreased as to be unprofitable.

Chemical Analysis does not Show Available Plant Food.—The reason for the apparent inconsistency between the analyses of soils and actual results in raising crops is found in the fact that the chemical analyses give the total amount of nitrogen, phosphoric acid and potash in the soil, but do not indicate what part of these foods is available to the plant The greater proportion of these substances is locked up in insoluble compounds, in which form the plant is incapable of using them. Smaller quantities have been changed by the forces of nature into a condition in which they are

available to plants. While the amounts of these materials removed by the crop seem insignificant when compared with the total plant food in the soil, they may be very large in comparison with the available part. The unavailable, or "potential," plant food is gradually being made available, but not with sufficient rapidity to replace that removed from the field at harvest. It will thus be seen that the present fertility of the soil depends not upon the potential plant food it contains,

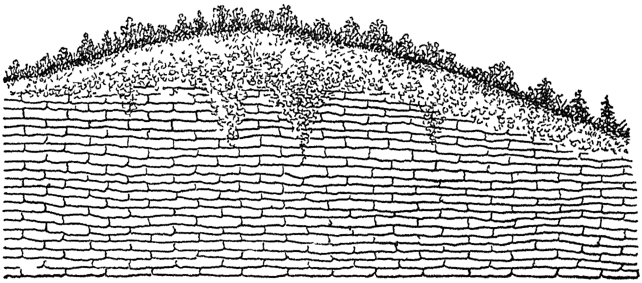


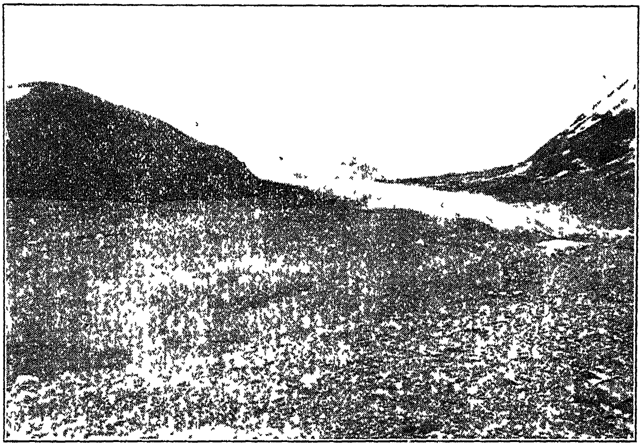
Diagram illustrating the formation of a soil on a limestone hill

but upon that which is immediately available to the plant, and that the yield will be limited by the element of this available plant food present in least quantity Continuous cropping of the soil with the removal of everything from the field results in the exhaustion of the plant food which has been rendered available during the past ages. It will be interesting to study the origin of the plant food, and the manner in which it became available to the plants.

CHAPTER V

ORIGIN OF THE SOIL

The Primary Soils.—All soils are derived primarily from the igneous, or original rocks, of which the granites and trap are good examples. Geology teaches that the earth was once a molten mass, and that upon



The glaciers were important factors in soil formation

cooling it solidified into rocks, of which those mentioned are types. These rocks must have contained all of the mineral or ash elements of plant food, as no other source of them is conceivable. This plant food, however, was present in insoluble compounds, and in

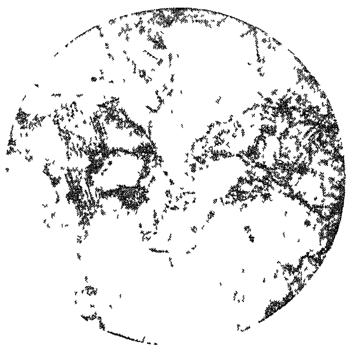
this form was not available to plants. The conversion of this potential plant food into available forms was brought about by a number of agencies. Fortunately these changes can be studied at first hand in the lava beds resulting from volcanic eruptions. These beds have been transformed in an incredibly short time from

The freezing of the water in the rock crevices helps to break the rocks into small particles

beds of solid rock into more or less fertile soils, by a series of changes much like those to be described.

The Rocks Must be Pulverized.—Evidently the first step toward the conversion of the solid rock into soil must have been the act of pulverization. A number of natural agencies have taken part in the grinding of the original rock into the small particles in which they are found in the ground The rocks have been

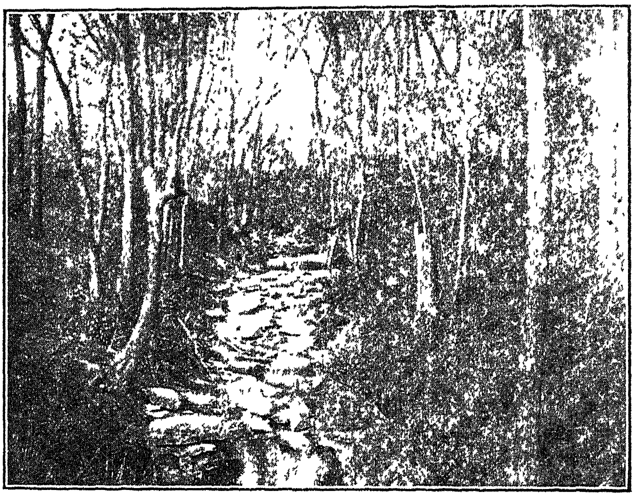
disintegrated through the influence of heat and cold, freezing and thawing, and by the action of air, water and ice. Such rocks as the granites, for example, can easily be seen to consist of several different minerals. These substances are differently affected by heat and cold, expanding and contracting at different rates, and for this reason the effect of changes in temperature is to separate the rock into its component parts. All rocks are more or less porous, and consequently, absorb water, and the expansion of this water when frozen tends to break the mass into fragments. Perhaps more important in this grinding process than either of these factors is the action of running water and moving ice in the form of glaciers. There is no need to discuss these forces in detail, for it will be sufficient for the present purpose if it be kept in mind that all of these influences combine to disintegrate and grind the surface rocks into smaller and smaller fragments, until they are reduced to the finest particles found in what is called the soil.



Microphotograph of a section of granite magnified 30 diameters (By courtesy Geological Department, Columbia University)

Plant Food Must Be Made Soluble.—A soil produced by mere pulverization of the rocks would not furnish proper food for the higher plants, as one can

readily imagine if he thinks how unsuitable pulverized granite would be for plant production. The essential elements locked up in these insoluble compounds must be transformed into materials that the plant can assimilate, and water is an important factor in bringing about these chemical changes. Pure water has very little

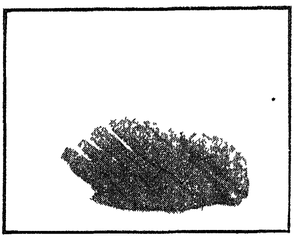


Running water is constantly changing the face of the earth, cutting out ravines and grinding the rock to powder

solvent effect upon the minerals of which the igneous rocks are composed. The water that enters the ground has dissolved in it small amounts of carbonic acid gas derived from the air, and water containing this gas will dissolve these minerals in appreciable quantities.

A Fertile Soil must contain Nitrogen.—All the processes enumerated unite in transforming the mineral

matter of the rocks into forms available to plants, but the mineral foods alone can not support the higher plant life. It has been shown that to grow crops the soil must contain available nitrogen, and this must have been derived originally from the air. In a previous chapter it was mentioned that small quantities of combined nitrogen are carried into the ground by the rain-water, and this amount, though very small, is probably sufficient to enable plant growth to begin. Some bac-



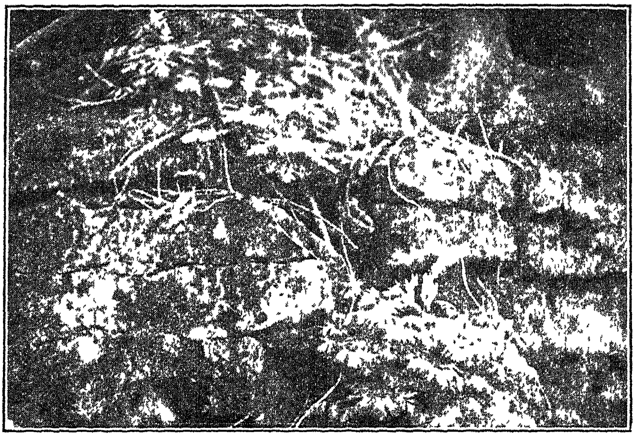
Effect of freezing on a piece of limestone

Mosses growing on granite boulder. They must have small food requirements or great powers of obtaining it

teriologists believe that the species of bacteria which can live upon mineral food alone, deriving all their nitrogen supply from the air, are important factors in the early nitrogen supply of the soil.

First Plants very Simple Organisms.—Vegetation begins with the very simplest forms of plants such as the lichens and mosses, and is, of course, very scanty at first. These plants on dying become a part of the soil, all of the plant nutrients used by them being thus returned. Food that has once been used by plants is very readily made available to succeeding crops, through the processes of decay and nitrification which

have been described. The soil is now able to produce a larger crop, as it contains the plant food in the previous growth in addition to that added through the agencies detailed above. In this way the growth gradually becomes more abundant The plants upon decaying give rise to humus, and this increases the

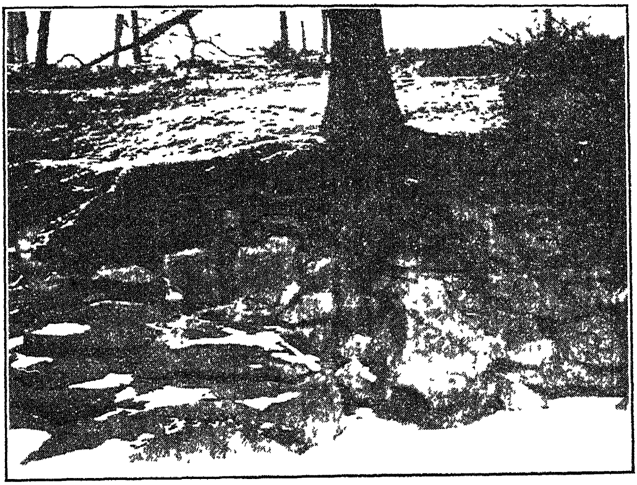


Effect of weathering on a limestone ledge. Notice that some plant or other takes advantage of every little accumulation of soil

fertility of the land, both by being a source of plant food, and by increasing the water-retaining power. It will be shown later that humus is a very important factor in fertility. During the decompositions of the plants, which give rise to humus, acid substances are formed which act upon the rocks in such a way as to make more of the plant food available. One of the products of decay or fermentation is carbonic acid gas, which is dissolved in the soil water, and this gas-con-

taining water is an important help in disintegrating the rocks.

Root Bearing Plants Important in Soil Formation.—As the nutritive materials increase from these various causes, the lower and simpler forms of plant life are gradually replaced by those which are more highly



The roots of plants are important factors in the pulverization of the rocks and the formation of the soil

organized. With the advent of plants bearing roots, other factors in the formation of soils are introduced. The roots secrete an acid substance that has a solvent effect on the mineral matter of the soil, and assist mechanically in breaking down the rocks. All are familiar with the tremendous force exerted by plants in breaking apart rocks and stone, if once their tender rootlets obtain a foothold in a crevice. The roots

penetrate the soil sometimes to great depths, and, as they decay after the death of the plant, they leave in the soil little channels which serve to carry down water laden with carbonic acid, as well as to introduce the oxygen of the air, which in its turn, is a factor in bring-

Fungi growing on an old stump. They hasten its decay and the return of the plant food to the soil

Lichens growing on rock. They are among the early agencies concerned in soil formation

ing about chemical changes in the soil which assist in making plant food available.

Legumes Increase Nitrogen of the Soil.—Sooner or later in the process of soil formation are introduced plants of the pulse family (leguminous plants) such as clover, vetches, lupines, etc., which can, through the agency of the nodule-forming bacteria in the soil, derive part of their food from the free nitrogen of the atmosphere. This peculiar property of leguminous plants is of paramount importance, for it is undoubtedly

Nature's principal method of increasing the supply of nitrogenous food in the ground. The nitrogen compounds accumulated by these plants eventually become a part of the soil through their decay, thus adding to its fertility.

Soil Results from Combined Action of Various Agencies.—It will be readily understood that the various agencies concerned in the formation of the soil do not act separately nor necessarily in any such order as

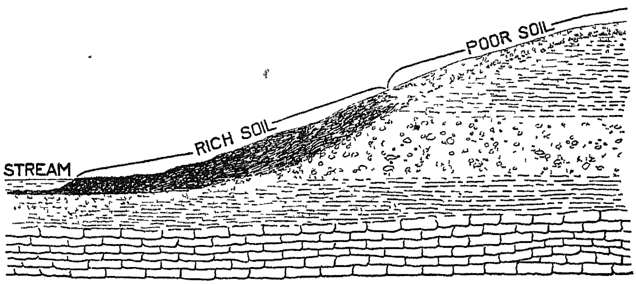
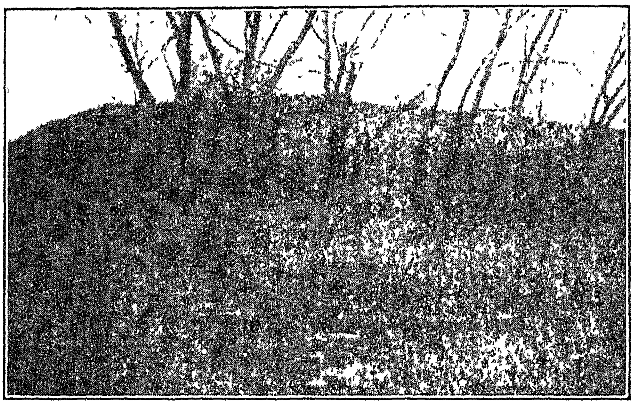


Diagram showing the movement of the soil from higher to lower levels

that in which they have been discussed. As a matter of fact, all the processes described take place simultaneously. The lower plants do not wait for the rocks to be pulverized, for we see such organisms as the lichens growing on rocks from which it would seem impossible for them to obtain food. If the lichen is removed, grooves or furrows will be found on the surface of the stone, due to the action of the plant. Nor are all soils formed directly from the original or igneous rocks, for one of the effects of weathering, etc., is to separate such rocks as the granites into simpler substances, with the result, for example, that huge de-

posits of limestone are formed in one place, and in another whole hills of sandstone.

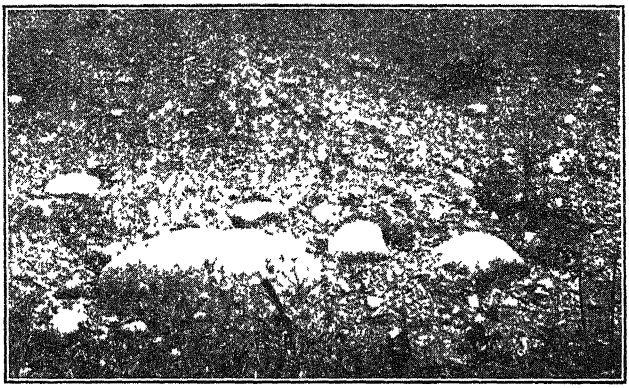
Movement of Soils.—The soil is almost constantly moving, for some of the same agencies which form soils are continually carrying them away. Running water grinds the rocks, but at the same time transports



Lakes, ponds and swamps are gradually being filled by the movement of the soil from higher to lower levels

the fine particles to lower levels. It cuts deep valleys in the surface of the earth and carries away the debris, depositing it at various distances from its source. Notice a stream muddied by a recent rain, the mud will be deposited somewhere to help form a soil. The soil is always moving from a higher to a lower level, consequently, it is thinnest at the top of a hill and deeper in the valley. Lakes and ponds are gradually filling up, and in time become fertile fields. If the pond is largely filled by the remains of the plants which have grown on it, a humus or peaty soil is formed.

Sedentary and Transported Soils.—Soils which have been formed from the rocks directly beneath them are known as "soils in place" or sedentary soils. These partake very nearly of the composition of the underlying rocks. Transported soils, on the other hand, may bear little resemblance in composition to the rock upon which they lie. Those deposited from water are



Drift soils are distinguished by the presence of rounded boulders. **They** are usually fertile though variable in composition

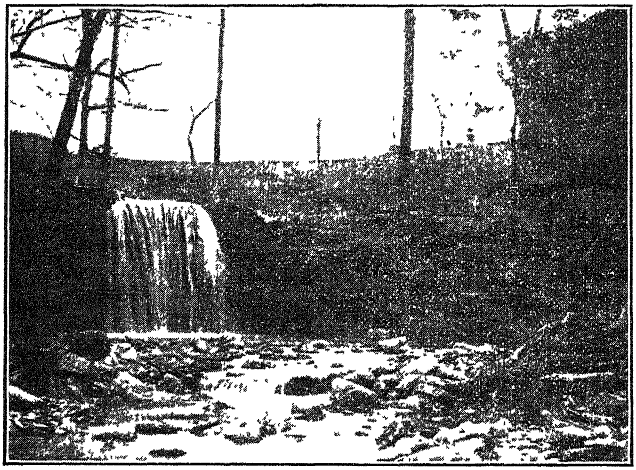
called "alluvial soils" and are found in the river valleys and in the beds of former lakes, and are usually very high in fertility. Those transported by glaciers are known as "drift soils." A large part of Northern United States is covered by drift which was pushed down from the north by the glaciers that once covered that section, and was left behind as the ice melted away. Drift soils are distinguished from all others by the presence of rounded boulders of various sizes, and are usually fertile, although very variable in composition.

Nature's Methods Contrasted with Man's.—The important lesson to be learned from a study of the origin of the soil is, that Nature undisturbed has many ways of adding to the supply of available plant food in the soil. The various forces that have been under discussion have all tended to change more and more the potential food into forms that can be assimilated

Nature undisturbed returns all the plant food removed from the soil, by the decay of the plants which it has produced

by the plants, so that the amount of vegetation which the soil can produce has been constantly increasing. Under natural conditions this growth is not removed from the ground, but is again made available, so that the land is constantly increasing in fertility. Thus it will be seen that the fertility of the virgin soils is the result of accumulations due to a variety of forces acting doubtless through countless ages, a period during which practically nothing has been removed from the soil while much has been added thereto.

Man, on the contrary, has reversed this process and while adding little to the soil has removed much therefrom. Through the constant harvesting of crops and leaving the ground bare and exposed to the action of the elements, he is rapidly depleting Nature's store of food, and the yield steadily becomes smaller. The effect upon the physical condition of the soil due to the



Who can tell how long it has taken this stream to cut this deep gorge in the limestone

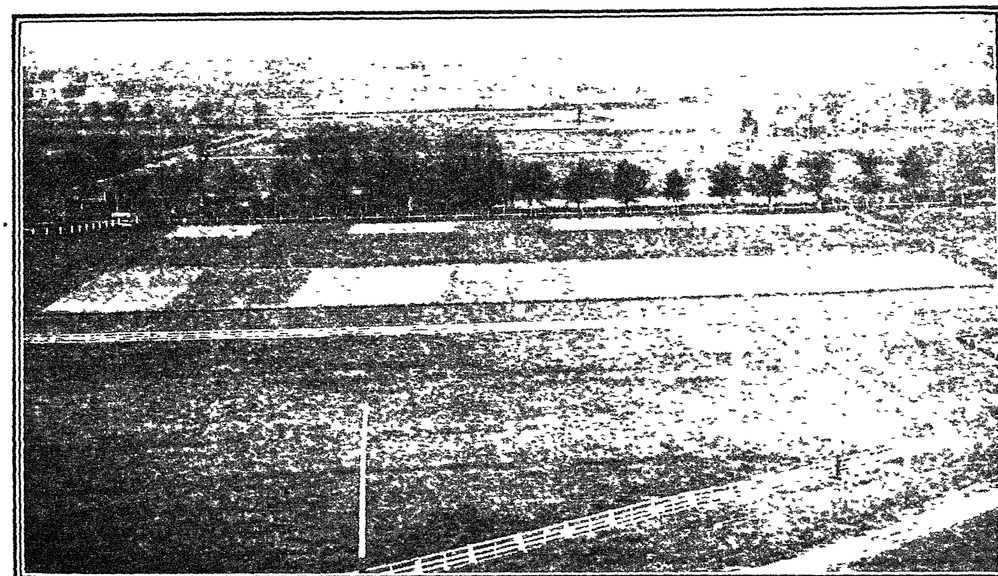
removal of all vegetation is serious, for in this way the soil is deprived of its humus-making materials, which is unquestionably quite as important as the actual loss of the chemical elements of fertility.

How to Prevent Exhaustion of the Soil.--Although Nature's method of maintaining the fertility of the soil is without doubt the most effective, it is of course im-

practicable for the farmer, for he must remove most of his crops from the field in order that they may be put to the various uses for which they are raised A study of the formation of the soil, however, suggests two things that he can do to prevent the exhaustion of the fertility. The first is so to treat the soil as to assist and hasten Nature in the process of converting potential plant food into available forms; and to guard against a too complete destruction of the organic matter in the soil. The second is to return to the soil an amount of nitrogen, phosphoric acid and potash equivalent to that removed by the crop.

PART II

'OTENTIAL PLANT FOOD AVAILABLE

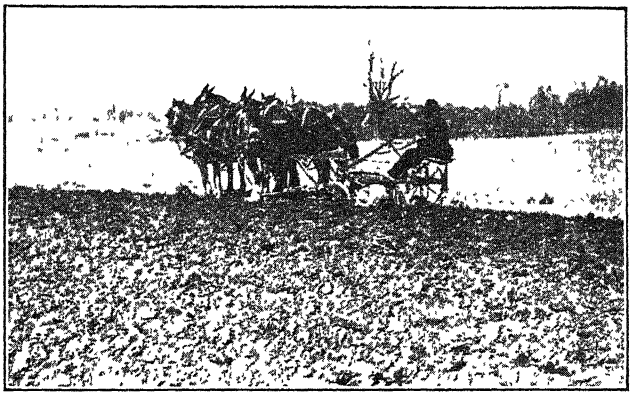


The effect of early spring plowing on the conservation of moisture. The darker plots were plowed earlier than the lighter ones and contained several tons more water per acre

CHAPTER VI

TILLAGE

Tillage Increases Feeding Ground for Roots.—The most efficient means of assisting nature in the conversion of unavailable food into forms that the plant



Plowing is the most important tillage operation It should be so done as to leave the minimum amount of work for the harrow, etc.

can use is good tillage of the soil Tillage, in the sense in which it is used here, signifies any operation of stirring and pulverizing the soil by means of plows, harrows, cultivators or any other implement, either before or after the seed is sown.

The most noticeable result of tillage is that the soil is made finer, the large lumps being broken up into smaller particles, and in this way Nature's work in the

formation of soils is accelerated. Pulverization of the earth is beneficial in many ways. In the first place, loosening the soil makes it easier for the plant roots and root-hairs to penetrate it. Mention has been made of the fact that all soils are composed of grains of greater or less dimensions separated by air spaces. The tender root-hairs must push their way in between these soil-grains, as it is impossible for them to penetrate the solid particles themselves. It must be evident that the more the soil is pulverized the larger the number of the openings between grains, and, consequently, the greater room for root growth.

The plant is dependent upon the root-hairs for its supply of mineral food and, as these hairs grow only between and around the soil grains, it is apparent that they can feed only on the surfaces of these particles. Good tillage increases the amount of surface exposed to the roots by breaking the large lumps into small grains; and the more complete the pulverization the larger the area from which the plant can obtain its food. The rapid increase of surface due to breaking down the lumps of a soil in poor tilth seems almost unbelievable to one who has given the subject no thought. An example will serve to illustrate what is meant: A cube, 2 inches on the side, presents a surface of 24 square inches. If this cube is cut once in each direction 8 cubes are formed, each one inch on a side, giving a total of 48 square inches of surface, so that cutting only once in each direction doubles the amount of surface. Thus, theoretically, a plant should be able to derive twice as much food from the eight small cubes as from the large one.

Tillage Hastens Chemical Changes in the Soil.—Stirring the soil is of great advantage in bringing together particles which have not before come into contact In this way chemical changes may take place that render potential plant food available, for substances having different chemical properties are thus

An incompleted soil. Good tillage will hasten the decomposition of the rocks

enabled to act upon each other The changes whereby potash and phosphoric acid become "fixed" in the soil are reactions of this class. The changes brought about by freezing and thawing may also be accelerated by proper tillage. This is made use of by some farmers who plow heavy, lumpy land in the fall so that it may be exposed to the influence of the weather during the winter. For this purpose the land is so plowed as to leave it rough and with the largest possible area exposed to the weather. Freezing and thawing bring about disintegration of the clods in much the manner mentioned in the chapter on formation of the soil, and the resulting improvement is most remarkable in some classes of soils.

Tillage Aerates the Soil.—One of the most advantageous results to be obtained from tillage is the aeration of the soil. The introduction of the oxygen of the air into the soil is of benefit in a number of ways. In the first place, a certain amount of air in the soil is necessary for the growth of all plants usually raised on a farm. The roots can not live without air any more than those parts which grow above ground. That air is needed by the roots can easily be shown by placing a pot containing any ordinary plant in a jar of water so that the soil will always be saturated. In a short time the bad effects will be noticeable on the plant. The plant does not decline because the water is injurious but because the presence of the water excludes the air from the roots. Oxygen is also necessary to the germination of seeds, for it is a well established fact that seeds will not germinate in the absence of oxygen.

The oxygen of the air has a direct chemical action upon the mineral matter of the soil in that it tends to make the latter soluble. It also prevents the formation of certain compounds (notably the sulphides of iron) which are injurious to vegetation.

Tillage Aids Nitrification and Prevents Denitrification.—All fertile soils contain a considerable amount of organic matter, and the presence of oxygen is necessary to its decomposition. Attention has been called to the fact that the soil contains innumerable bacteria, a part, at least, of which are concerned in the decay of organic matter, and those which are beneficial to the farmer can not live without oxygen. One class of these bacteria decomposes a part of the organic matter

with the formation of carbonic acid gas, and it has been shown that this gas dissolved in the soil-water is a great factor in making plant food soluble. As this decomposition goes on more rapidly in well aerated soils it will be seen that this is one reason for the increased fertility due to thorough tillage. The nitrifying bacteria previously mentioned thrive only in the presence of a sufficient supply of oxygen. Most of the nitrogen of the soil is locked up in insoluble organic compounds, and before it can be used by plants it must be converted into the form of nitrates. This process takes place only in a soil well supplied with oxygen, and experience has proven that this process is very materially hastened by frequent cultivation. The extreme importance of this process of nitrification has already been commented upon, and it remains only to say that tillage would pay for itself if it did no more than hasten nitrification.

Thorough aeration of the soil prevents the action of the denitrifying bacteria, as these bacteria thrive best in a soil devoid of oxygen. Acidity of the soil is also favorable to the growth of the denitrifying bacteria, and as the presence of sufficient oxygen in the soil tends to keep it sweet it is thus helpful in preventing denitrification.

The bacteria which enable leguminous plants to use free nitrogen are also dependent upon the air in the soil, for not only do they need oxygen, but experiments have shown that it is only from the air in the soil that they can draw their supply of nitrogen. It is necessary, therefore, in order that leguminous plants may profit by the nodule-forming bacteria, to have the soil

in such condition of tilth that the air may freely circulate through it.

Tillage Increases Amount of Available Water.—Tillage not only increases the amount of surface on which the plants can feed, but at the same time enlarges the water supply by giving the soil greater capacity for holding moisture. Attention has been called to the fact that each soil-grain is surrounded by a film of water which is called the capillary water or film moisture. The plant is dependent upon this film moisture for its supply, and it is readily seen that the amount of capillary water that the soil can retain depends upon the aggregate surface area presented by the particles of which it is composed. The rate at which this area, and the consequent amount of available moisture increase, is strikingly brought out by King in his book entitled "The Soil" from which the following is quoted: "Suppose we take a marble exactly one inch in diameter. It will just slip inside a cube one inch on a side, and will hold a film of water 3.1416 square inches in area. But reduce the diameters of the marbles to one-tenth of an inch, and at least 1,000 of them will be required to fill the cubic inch, and their aggregate surface will be 31.416 square inches. If, however, the diameters of these spheres be reduced to one-hundredth of an inch 1,000,000 of them will be required to make a cubic inch and their total surface area will be 314.16 square inches. Suppose, again, the soil particles to have a diameter of one-thousandth of an inch. It will then require 1,000,000,000 of them to fill completely the cubic inch, while their aggregate surface must measure 3141.59 square inches." Another way of

stating the same fact is that if an acre of ground is so tilled as to reduce the average diameter of the soil particles to one-tenth the original diameter, the plant now has ten acres from which to draw its supply of water and mineral food for each acre it had before;

The old-fashioned home-made planker is sometimes very useful for pulverizing the soil

and the soil is enabled to hold as film moisture ten times as much water as it could in the first instance

Tillage to Conserve Moisture.—From what has been said regarding the importance of water to the plant it must be apparent that one of the chief problems of agriculture is to maintain a proper degree of moisture in the soil. It seldom happens that a crop can obtain from the soil the amount of water necessary for a maximum yield, and great skill is required to keep it from suffering for lack of moisture during the hot summer period of scanty rainfall While man can do nothing in the way of distributing the rainfall through-

out the growing season, he can, by a judicious use of tillage methods, do much toward saving the excess of moisture precipitated in the early spring, for the use of the plant during the drier weather of the summer. One way in which tillage accomplishes this end is by increasing the capacity of the soil for storing water, as described in the preceding paragraph. It must also be evident that the loosening of the ground incident to tillage makes it easier for the rain to enter the soil, and tends to prevent loss by surface washing, as the water sinks into the soil instead of running away. Special mention might be made here of the "earth mulch" and late fall, and early spring plowing, as methods of tillage especially recommended for the conservation of soil moisture.

The Earth Mulch to Conserve Moisture.—During dry weather water is constantly being evaporated from the surface of the ground. Under ordinary conditions, where the soil is somewhat firm, water is drawn up from below by capillary attraction to replace that removed by evaporation. As this may be very rapid in the hot dry weather of midsummer the result is that the water is virtually pumped out of the soil until it is too dry for good plant growth. If something is done to break this capillarity the water can not be brought up from below. This is the end accomplished by the earth mulch, which is simply a layer two or three inches deep of very dry soil, so dry and loose that it can not take up the water from the layer next beneath it. The same end can be attained by covering the ground with loose straw or other similar material, the principle underlying both kinds of treatment being the same.

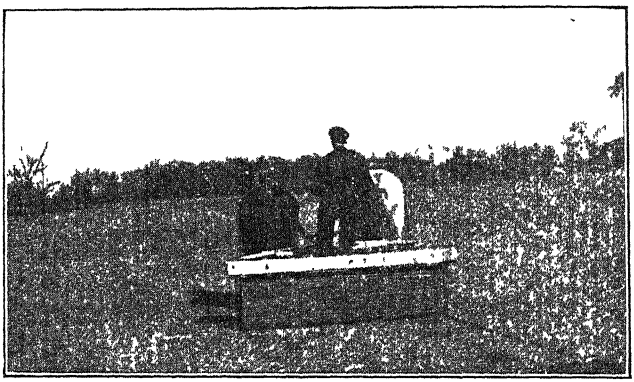
To make an effective earth mulch the cultivation should be shallow and frequent, the aim being to make the layer as dry as possible A rain, of course, will again compact the loose earth, and renew the capillarity, so that the cultivation should be repeated as soon as may be after a rain Even in the absence of rain the mulch will sooner or later become compact of itself if left too

Soil which is badly in need of tillage The cracks allow large amounts of water to be lost by evaporation

long without stirring. It is desirable to loosen the soil more frequently in the spring than is necessary later in the season. A mulch about three inches deep has been found to be most effective in conserving moisture, and it has also been shown that mulches produce relatively better results in sandy soils than in clay or loam.

Late Fall Plowing to Conserve Moisture.—Plowing the ground late in the fall tends to save the moisture, as the loose ground turned up by the plow prevents loss of water by evaporation. The broken uneven

surface also makes it possible for the soil to absorb more of the water from the winter rain and snow. An experiment reported from Wisconsin shows that a plot plowed in the fall contained 1 15 acre inches more water than an adjacent plot not so plowed. It must be borne in mind, however, that fall plowing is not a practice



The tube roller crushes the clods without compacting the soil so much as the solid roller

capable of universal application, for there are certain hard soils with a low humus content which may be badly puddled if fall plowed. Here, as everywhere in farming, good judgment is called for on the part of the farmer.

Early Spring Plowing to Conserve Moisture.—Plowing the ground very early in the spring is a rational practice, for there is no other season when tillage is so effective in conserving the moisture of the soil. King reports one experiment where early plowed ground, seven days after plowing, contained an amount

of water equal to 1.75 inches in excess of an adjoining plot which was not plowed Quiroga, in a thesis presented to the College of Agriculture, Ohio State University, reports that the moisture content of the early plowed plots was higher than the late plowed throughout the season. He found also that the available nitro-

Weeds are objectionable because they remove large quantities of water and available plant food which are needed by the crop

gen was much higher, in the early plowed plots, and that the yield of corn was greater. All evidence indicates that the soil should be stirred as early in the spring as can be done without injury to its texture, either by plowing or by the use of some form of cultivator or harrow.

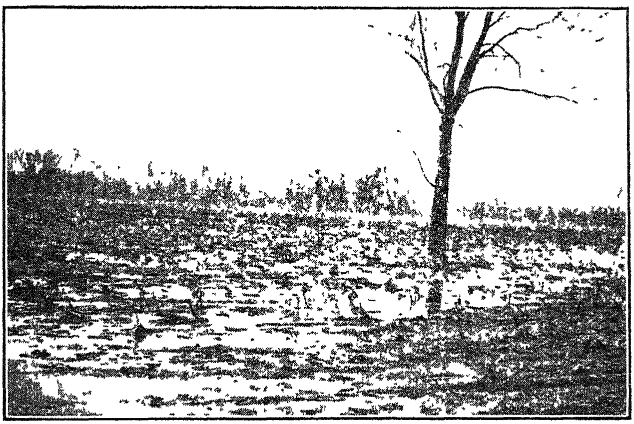
Tillage Destroys Weeds.—Lastly, tillage is useful in destroying weeds. Weeds should not be permitted to grow because they rob the crop of its moisture and plant food. During growth all plants pump up water by means of their roots, and give it off through the leaves It has been shown that at the best the supply

of water in the ground is seldom sufficient for a maximum crop so that any withdrawal of water from the soil by the weeds works a positive injury to the desirable plants. While it is probable that the weeds do the greatest injury to the crop by depriving it of water, they also rob it of nitrogen and mineral food. Some farmers argue that if the weeds remain on the ground they are removing no fertility, but it must be remembered that they are using that portion of the plant food that could be used by the crop and that the weeds must decay before this food is again rendered available, so that so far as the present crop is concerned the food is as completely removed as it would be if taken from the field. The destruction of weeds was formerly regarded as the only reason for tillage after seeding It is now known that stirring the soil has a distinct value in itself, and that the killing of the weeds is really secondary In fact if the farmer so tills his farm as to reap the maximum benefits to be derived from this process he will have no need to worry about the weeds.

CHAPTER VII

DRAINAGE AND IRRIGATION

Film Moisture and Ground Water.—An important method for increasing the fertility of some classes of soils is that of underdraining by the use of tile or



A wet soil is a cold soil Dry, well drained soils become warm earlier in the spring than those which are wet

other means. Water exists in the soil in two principal forms, viz: as the film or capillary moisture previously discussed, and in the form known indiscriminately as free water, ground water, or hydrostatic water. In the latter condition the water occupies the spaces between the soil grains, and is not held by the attraction of

these particles. The surface level of this free water is known as the "water-table," and is situated in some soils very near the surface while in others it is many feet below. The exact height of the water-table can be readily ascertained by sinking a hole to such a depth that water will stand in it, the level of the water in the hole being practically that of the water-table. It is this free or ground water that supplies shallow wells and the ordinary springs. In some cases the water-table may be at the level of the ground or above it, as is obviously the case where marshes and lakes exist.

High Water-Table Objectionable.—When the level of the free water is near the surface of the ground, the soil will be greatly benefited by some system of under-drainage, as this hydrostatic water is, for several reasons, injurious to the crop. Ground water limits the feeding space available to the plant, and, consequently, the amount of food it can obtain. Those plants that are of importance to agriculture must have their roots supplied with air, and investigations have shown that such plants do not send their roots below the water-table, because the spaces between the soil particles below this level are filled with water, thus preventing the entrance of air. In other words, the depth to which the plant will send its roots is determined by the position of the water-table.

Free water makes the soil cold. A great deal more heat is necessary to warm water a certain number of degrees, than is required to raise the temperature of an equal weight of the dry matter of the soil to the same amount. A soil, therefore, that contains much water is harder to heat than one that is comparatively

dry. A very wet soil causes plant-food to become locked up in unavailable forms, and in some cases compounds are produced which are actually poisonous to the desirable plants. An excessive amount of water in the soil also dilutes the plant-food in solution and makes it more difficult for the plant to procure sufficient nourishment.

One of the most important considerations in this connection is the fact that the presence of free water

A place that calls for underdraining. Such spots are a menace to the health as well as being unprofitable

in the soil prevents nitrification and promotes denitrification. In water-logged soil nitrates are rapidly decomposed, the nitrogen being given off to the air in the free, or elemental condition; and for this reason not only is the nitrogenous food in the soil destroyed, but the application of nitrogen fertilizers to such a soil results in great waste of this valuable element of fertility.

Drainage Aerates and Warms the Soil.—Underdraining the field results in lowering the water-table

to the level of the drain, the water flowing off through the tile instead of standing near the surface as stagnant water. A few ways in which this is of benefit to the soil may be indicated The removal of the free water from the soil above the drain allows the entrance of air, and for that reason increases the depth to which the roots will penetrate The entrance of air with its oxygen and carbonic acid, and the consequent greater depth reached by the roots and earthworms, are factors of importance in improving the texture of the soil. The

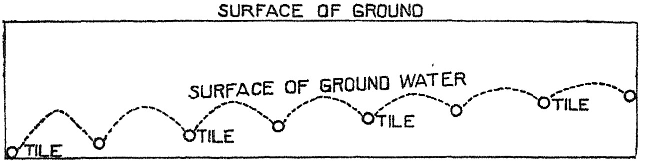
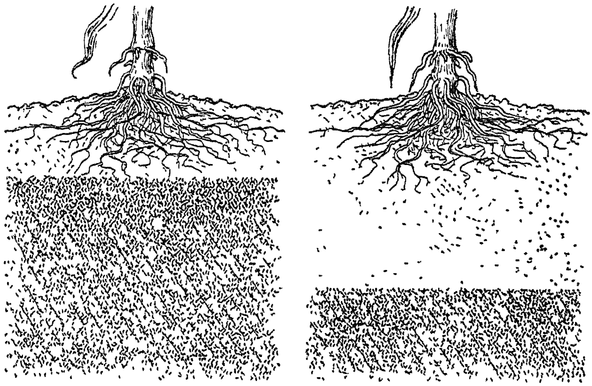


Diagram showing the level of the ground water in a tile-drained field a few hours after a heavy rain

rains will now soak down through the soil rather than run off the surface, and in this way the nitrogen in the rainwater is added to the soil, and surface washing is to a certain extent prevented Rain in the spring is warmer than the ground, and as it percolates through the soil has a beneficial effect in warming it, thus putting it in condition to promote plant growth much earlier in the season. Evaporation of water from the surface of the soil tends to keep it cool, and as the amount of water near the surface is decreased by drainage, evaporation is also lessened. Well drained lands, therefore, maintain a higher temperature throughout the season than do those containing much free water. Drainage lengthens the season of plant

growth and promotes nitrification and other processes by which the plant food is made available.

Drainage increases Available Water and prevents Injury from Drouth.—Paradoxical as it may seem, underdraining increases the amount of water available to the plant. The crop depends almost entirely on the capillary or film moisture for its supply of water, and

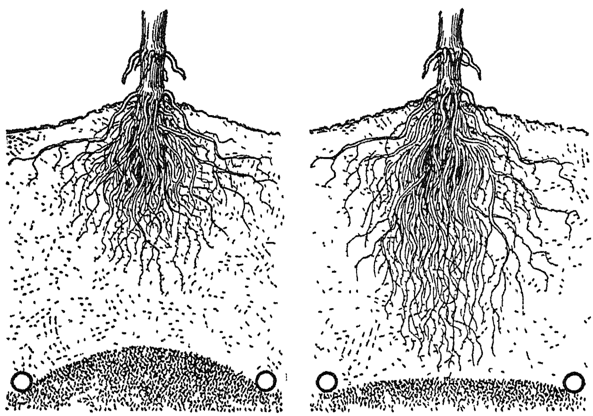


In cold, undrained lands, where the water-table in the spring is high, the plants are shallow rooted, and when the drouth of summer lowers the water-table they suffer for lack of moisture

as has been said, the roots do not enter that part of the soil containing free water. Lowering the water-table greatly increases the total amount of film moisture, as all that part of the soil from which the free water has been removed is capable of holding capillary water. Thus it will be seen that while the total amount of water in the soil is decreased by drainage, that which is of use to the plant is made much greater.

Drainage prevents injury from drouth, for by means of it the plants are encouraged to make deeper root

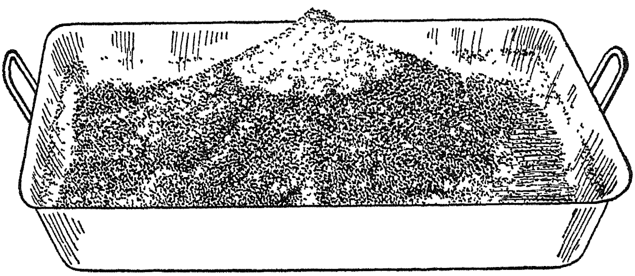
growth, and, hence, are not so easily affected by the extreme drying of the surface of the ground that takes place in times of scanty rainfall. It will readily be seen that tile draining determines the highest point the water-table can reach, but that in dry weather the level of the ground water may be much below the drain. It is sometimes thought, for this reason, that part of the



Good drainage encourages the roots to strike downward and when the drouth comes the plants do not suffer

water from summer rains, which would otherwise be absorbed by the soil below the drain, may be lost through the tile. Experience has shown, however, that the water does not percolate into the drain as some suppose, and that it is only when the rainfall is sufficient to raise the water-table to the level of the drain, that any water is removed by it. It is a matter of common observation that, except in the case of quite low lands, it is only the very heavy summer rains that

cause the drains to run. It will thus be seen that it is simply the excess of water which is removed by underdraining, and not that part which is of most importance to the plant. Although the crop probably makes little direct use of the free water, one must not lose sight of the fact that it may be drawn into the upper layers of the soil by capillarity to replace that lost by evapora-



Experiment to show how water is drawn to the surface from the lower levels of the soil by capillarity. (Drawn from photograph)

tion, and for this reason the underdraining should not be so deep as to interfere seriously with capillary action.

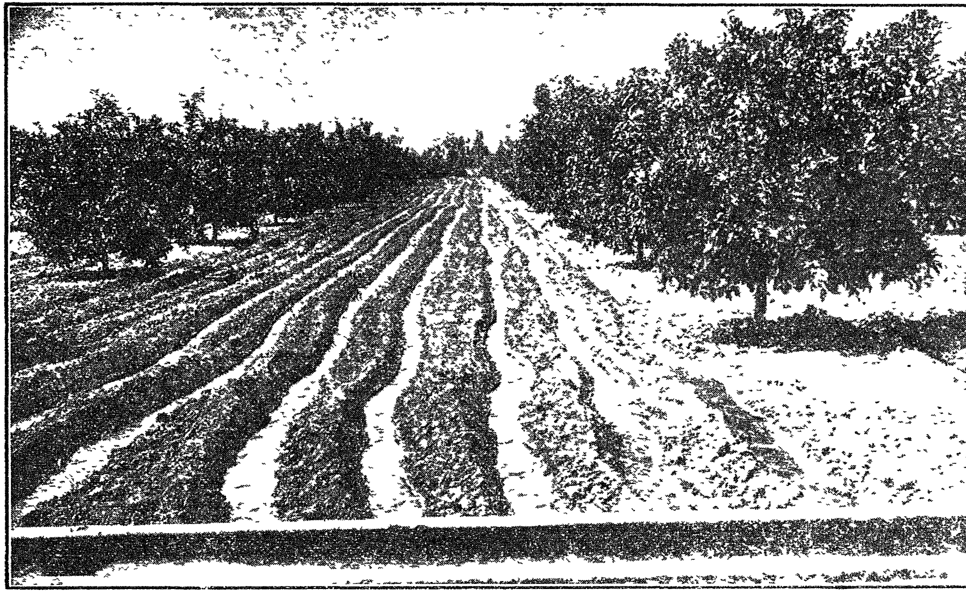
Drainage Sometimes Beneficial on High Lands.—Strangely enough, experience has shown that it is not merely low lying soils which are benefited by underdraining. In many cases heavy clay soils in elevated positions, especially if underlaid by rather impervious subsoils, are greatly improved in tilth by tiling. In such soils the percolation is so slow that practically the same effect is produced as would be expected if the general level of the ground water were near the surface. These soils are made more mellow by drain-

age and respond more readily to early tillage. Clay soils are often puddled by the fine particles in the soil-water being deposited in the spaces between the soil-grains, thus cementing them together The use of tile will often prevent this by causing the water to sink more rapidly through the soil. Tile-drained fields are not so likely to be injured by hauling heavy loads over them as are those not so treated

Irrigation in Humid Climates in Experimental Stage.—There are large areas in the western part of this country which, for lack of sufficient water, produce very scanty vegetation, although in many instances the soil is well supplied with the other materials essential to the plant The results to be derived from irrigation on such soils is too well known to call for comment here. The work of investigators, notably that of King, in the so-called humid climates east of the Mississippi has shown that even here the total rainfall is seldom sufficient for a maximum yield of the staple crops, and the precipitation is distributed so unevenly throughout the season that a comparatively small part of it can be used by the plants.

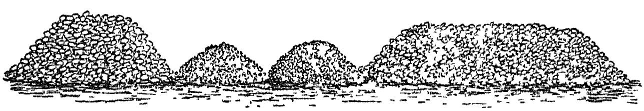
Many market gardeners recognize the fact that some system of irrigation is necessary for the most profitable returns, and are in the habit of supplying water artificially to their more valuable crops. Marshall P. Wilder when asked to name the three things most essential to successful strawberry culture is said to have replied: "First, plenty of water; second, more water; third, still more water."

At the present time irrigation of the staple farm crops is not practiced to any large extent in the humid



Furrow Irrigation of a California Orchard
(Photo by courtesy office of Irrigation Investigation United States Department of Agriculture)

parts of this country. King has shown that the yield of these crops can be greatly increased by supplementing the rainfall with irrigation. Two examples will suffice: An average of two crops of potatoes gave an increase of 105 bushels per acre due to irrigation. In 1894 he reports a crop of flint corn yielding 14.5 tons of dry matter per acre on an irrigated plot while the same corn yielded not more than 4 tons when receiving only the natural rainfall.



Increased yield of potatoes as a result of irrigation in humid climate (Wisconsin). The irrigated plots represented by the two piles on the right yielded 105 bushels more per acre than the unirrigated on the left. (Drawn from half tone)

It is more than probable that the future will see irrigation in extensive use east of the Mississippi, but at the present time it is only in the expermental stage, and it has yet to be demonstrated that it will be profitable with ordinary crops under practical conditions. It is to be hoped that experiments along this line will soon be made, but they should be undertaken only by men who have made a study of the subject, for in humid climates irrigation in untrained hands may produce more harm than good.

CHAPTER VIII

SUMMER FALLOWING

Origin of Fallowing.—The practice of fallowing or "resting" the land is a very old one, being mentioned in the twenty-fifth chapter of Leviticus, where the people are commanded to rest the land every seventh year. "The seventh year shall be a sabbath of rest unto the land." It is not known if this law was introduced into the Jewish code from a knowledge of the effect of fallowing on the soil, or if it had more to do with the mystical meaning that seems to be associated with the number seven in the Hebrew religion.

A study of the history of agriculture leads one to believe that when the nomadic tribes first settled down to anything like systematic cultivation of the soil, they grew one crop (probably of the wheat family) continuously on the same field, until the soil became so impoverished that it could no longer be tilled with profit. They then moved to other sections where virgin soil was to be found, and repeated the process. In the course of time it was discovered that these lands which had been abandoned would again produce good crops after a period of "rest" as it was called. This led to the practice of cropping the land one year, and allowing it to lie idle the next. It was later discovered that if the soil was frequently stirred during its resting period the growth the following year would

be much more luxuriant than if the ground was left undisturbed. From this beginning arose the practice of summer or bare fallowing as it is understood to-day Later experimenters found that practically as good results could be obtained by the use of the so-called "fallow crops" in place of the year of rest. These are simply crops like Indian corn, turnips, potatoes, etc., which are intertilled and kept free from weeds during at least a part of their period of growth, and their introduction has practically done away with the use of the bare fallow in most localities.

It is now well understood that what was formerly called resting the land is in reality a method of bringing about ideal conditions for the transformation of potential food into forms available to the plant. This practice of fallowing the land has practically fallen into disuse, but is being so strongly advocated in some quarters at the present time that it seems proper briefly to discuss the subject here.

Fallowing adds nothing to the Soil.—The chief advantages claimed for summer fallowing are: (1) It makes plant food available, thus increasing the succeeding crop. (2) It enables one to rid the land of weeds. (3) It destroys large numbers of injurious insects. It is doubtful, however, if under good conditions of tillage and soil management, fallowing is ever necessary. It adds nothing to the soil, but merely presents conditions that are favorable to the conversion of potential plant food into available forms; and the increase in the crop following the fallow is seldom sufficient to recompense the farmer for the year of non-production. The crude methods of culti-

vation in use in earlier times doubtless made fallows necessary, but the introduction of modern machinery,

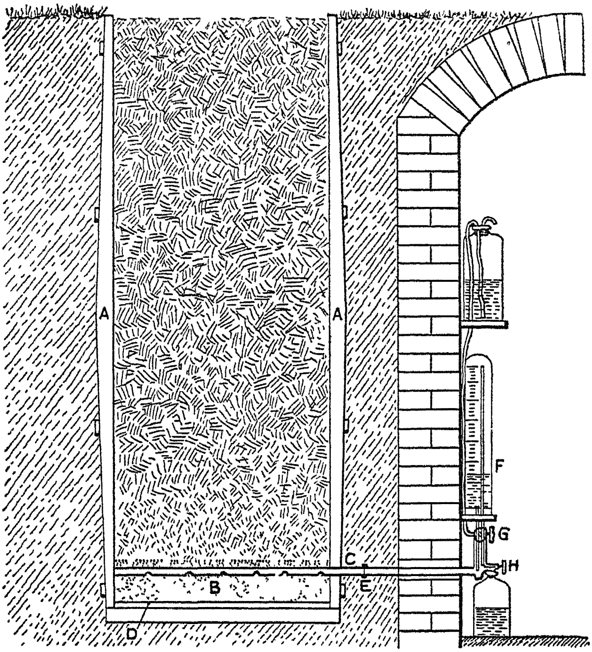


Diagram showing the construction of the lysimeter used at the New York State Experiment Station to study the loss of nitrogen from the soil by leaching

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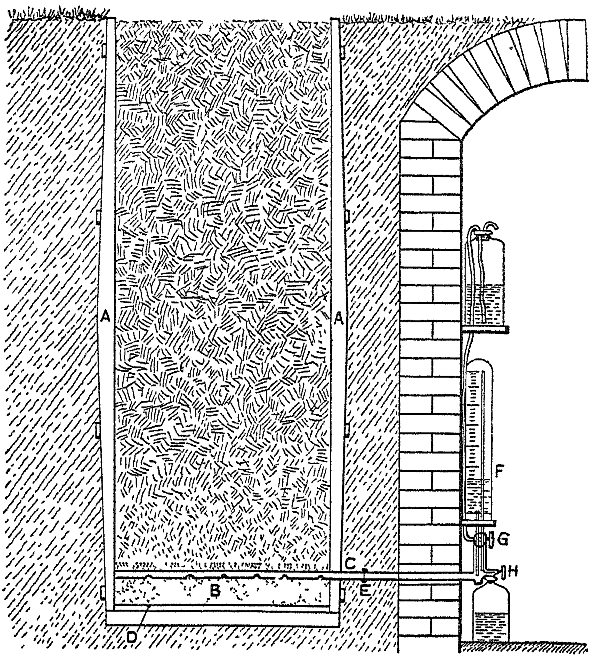

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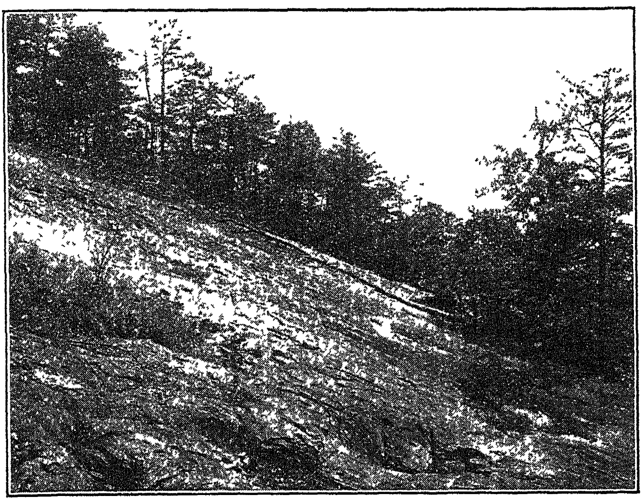
which hasten nitrification, for it has been shown that the nitrifying bacteria thrive best in a warm, well aerated soil. The result of fallowing is, that during the hot summer months the process of nitrification goes on very rapidly, and as there is no growth to remove them, the nitrates accumulate in the soil in large quantities.

Nitrogen May be Lost Through Fallowing.—Attention has been called to the fact that the nitrates are easily leached out of the ground if present in any considerable amount. One of the dangers of the practice of fallowing is that if the land is left bare during the heavy rains of fall and winter, a large part of the nitrates formed during the summer months may be lost in the drainage water, a state of affairs that is to be avoided if possible. Snyder in a Minnesota bulletin reports an experiment in which for every pound of nitrogen made available by fallow treatment, five pounds of total nitrogen was lost from the soil. At the New York Experiment Station at Geneva, tests were made to determine the loss of nitrogen in drainage water. Lysimeters were constructed to simulate natural conditions as nearly as possible and yet allow the collection of the drainage water. Grass was grown on one of these lysimeters, being frequently mowed, as is done on a lawn. The soil in another was kept bare, no plants at all being allowed to grow, and the surface was frequently stirred. The drainage water from the lysimeters was all collected, and the nitrogen determined. It was found that in the case of the lysimeter on which the sod was growing, practically no nitrogen was lost in the drainage water,

while in the other the loss of nitrogen amounted to from 218 to 357 pounds of nitrogen per acre each year. There is no doubt that these figures are in excess of the loss that would actually occur under field conditions, as the drainage in the lysimeters was perfect, and the effect of capillarity was probably less



Sometimes the same forces which make soils destroy them as well. This granite knob was once covered with soil which has been washed away, probably as a result of the removal of the forest

than would have obtained in the field. They show, nevertheless, in a marked way the danger of great loss of nitrogen if the summer fallow is followed by heavy fall rains. In these experiments it was found that the loss was small in the summer months, nearly all of it occurring during the fall and winter. This loss of nitrogen amounts to from two to four times that

removed by a crop of corn, and it will be remembered that it is the nitrogen which is in the form most available to plants that is lost by leaching.

Growing Crops Prevent Loss of Nitrogen.—These experiments are interesting also because they show how slight is the danger of loss of nitrogen if a crop is kept growing on the land. Numerous other experiments have confirmed this observation that if the field is covered with a growth of plants practically no nitrogen is lost in the drainage water, not because the nitrates are not formed but because the plants appropriate them as fast as they are produced. If then, the field which has been lying idle during the summer is planted to a crop before the fall rains begin, the loss of nitrogen will probably be prevented. The whole secret of preventing the waste of nitrogen from the soil is to have some crop on it during all the growing season. Nitrification takes place very slowly after the warm weather of summer has passed, so there is little danger of loss of nitrogen through leaving the ground bare in the late fall, provided a crop has been growing on it during the period that was favorable to nitrification. For this reason there need be no fear of loss of nitrogen as a result of fall plowing.

Another Point of View.—There are, however, two sides to the question of the desirability of summer fallows. King cites experiments of his own which show (by determinations made April 30) that the plots which had been fallow the previous year contained 245 pounds more nitrate nitrogen per acre than the corresponding plots on which crops had been produced. His experiments further showed that the

crop was harvested, and the stubble only plowed under. At the Rothamsted Experiment Station it has been estimated that 50 pounds or more of nitrogen per acre is added to the soil in the roots and stubble of clover alone.

Catch Crops for Green Manuring.—Where it is not advisable to devote an entire season to the growth of a crop for green manuring, good results may often be obtained by growing "catch crops" between the profit crops. The use of cover crops on orchards, and as a protection to the land during the winter, are modes of green manuring. As far as possible leguminous plants should be used for this purpose. The assertion is frequently made that by good tillage, and a judicious use of leguminous crops, the fertility of the soil may be maintained indefinitely without the use of fertilizers of any kind. The writer feels that this point has yet to be demonstrated, but no one doubts that these plants are of great value in the conservation of fertility.

Danger from Green Manuring.—While green manuring is a valuable method of increasing the humus supply of the soil it is not unattended by danger. In a dry season, for instance, the growth of a crop to plow under may result in lowering the moisture content of the soil to a point that is detrimental to the succeeding crop. There is also danger in such a season that there may not be sufficient moisture in the soil to bring about the decomposition of the organic matter which is turned under, resulting in serious injury to the physical condition of the soil. If a crop is plowed under during a dry season the ground should

be rolled, or otherwise firmed, so as to renew capillarity as far as possible.

Green Manuring Not Advisable on Stock Farms.—Green manuring as a general practice is not to be recommended in any style of stock farming. The

Crimson clover as an orchard cover-crop. The cover-crop is one method of green-manuring, and the crimson clover is a good example of the nitrogen-gathering plants used for this purpose

crops which are most valuable as green manures are also of great value as feeds, and it will be found more profitable to feed them to the animals and return the manure to the field, as will be shown later. On the whole, it may be said that green manuring will prove desirable in any system of farming (including truck farming) where the crops are sold from the farm, and

especially if all the crops produced are much alike in food requirements. On the other hand, if the farmer is engaged in animal husbandry the crops are of such great value as feeds that turning them under must be considered a wasteful practice.

CHAPTER X

ROTATION OF CROPS

Origin of Rotations.—It is the common experience of farmers in those parts of the world where the land has been cultivated for a long time, that the fertility of the soil is maintained for a much longer time by growing a variety of crops instead of producing one crop continuously. The adoption of a system of rotation of crops has been the outgrowth of accident rather than the result of an understanding of its underlying principles. The system of alternating years of bare-fallow and wheat may be said to be a two year rotation and was the first to be adopted. History teaches us that this was later followed by a three year rotation consisting of fallow, wheat, beans or oats; and still later, when the value of clover and fallow crops became evident, this rotation gave way to the now famous Norfolk rotation of turnips, barley, clover and wheat, the typical English rotation. The Norfolk four year course represents the more common type the world over, consisting as it does of cereals alternating with hoed crops and leguminous crops.

Plants Differ in Food Requirements.—There are many arguments to be advanced in favor of growing a variety of crops on the soil. The different crops vary in their food requirements and in their ability to procure this food from the soil. Where one crop is grown

continuously on the same field nearly all of the plant food available to that crop may become exhausted, while the soil would contain large quantities of food in forms that could be assimilated by plants of another class. Some crops evidently require the mineral matter to be in a readily soluble form, while others can use "tougher" forms of plant-food. The early writers on agricultural chemistry supposed that the crop during its growth excreted substances that were injurious to itself, while they were at least harmless and perhaps beneficial to plants of a different class. This view is not now accepted, but it is believed that the failure to produce profitable results where one crop is grown continuously is due to the exhaustion of the forms of plant food available to that particular crop. Some crops make an especial drain on one element of plant food. By growing crops with different food requirements there is less likelihood of any one element becoming exhausted and the different elements are more evenly used.

Plants differ in Manner of Growth.—The various crops differ widely in their systems of root growth. Some plants like wheat are comparatively shallow rooted, and must obtain their food from the surface soil, others, as the clovers are very deep rooted, and are able to use food that would not be within reach of the more shallow rooted plants. The deep rooted plants can not only procure the low lying food, but probably bring a part of it to the surface where it remains upon their decay for the use of the succeeding crop. It is well known that the shallow rooted plants do better when preceded by a deep rooted crop.

Rotation Improves Soil and Economizes Labor.—When a variety of plants is grown the soil receives different treatment for each crop, so that the faults of one year are likely to be corrected the next, and for this reason, the soil is kept in much better physical condition As a general rule the ground can be better prepared for the succeeding crop if a judicious rotation is practiced than if the same crop is grown continuously. The roots and stubble of clover and the grasses are also factors of some importance in improving the texture of the soil. Taken altogether the texture or tilth of the soil will be found to be much improved by rotation of crops.

Where a variety of crops is grown on the farm it results in economy of labor, for the work of caring for them is distributed throughout the season instead of all coming at one time In this way it makes it possible to secure cheaper and better help than where only a few kinds of plants are produced.

Rotation Aids in Controlling Diseases, Insects, and Weeds.—Rotation also enables the farmer to control plant diseases and to head off the injurious insects. Most of the plant diseases are caused by bacteria or other fungi which live only on one genus of plants, or at any rate, are more or less restricted in the number of crops that they can use as host plants. Where one crop is grown continuously these disease-producing fungi are given every opportunity to be carried over from one year to another. Most of these germs are comparatively short lived, so that if three or four years of crops that are not suitable host plants intervene the germs are likely to be destroyed. In the same way

it may be said that the injurious insects are limited to certain plants for their food supply, and if these plants are not grown on the field for a number of years the insects may die from starvation. These remarks do not apply, of course, to those insects which have migratory powers. There is no doubt, however, that both diseases and insects can be more easily suppressed if rotation is practiced. Where one crop is grown continuously the soil becomes infested with certain weeds which are not destroyed by the system of tillage necessary for that crop. The varying treatment to which a soil is subjected in a well planned rotation makes this condition impossible so that the destruction of weeds may be considered as one of the very desirable results of a rotation of crops. In lands badly infested with particular weeds it may even be desirable to omit from the rotation for a while the crop whose growth presents the best condition for their propagation.

Effect of Rotation on Crop Production.—The effect of rotation on crop production is strikingly shown in the following table compiled from data furnished by the Rothamsted Experiment Station.

EFFECT OF ROTATION ON CROP PRODUCTION—AVERAGE OF EIGHT COURSES (32 YEARS)

	Bushels per acre	
	Barley	*Wheat*
Grown continuously	18	12
In rotation	32	26

The rotation was the Norfolk rotation consisting of turnips, barley, clover and wheat, each grown one year, and the figures given are the average of eight crops

each of barley and wheat, representing a period of 32 years. The experiments with wheat and barley grown continuously on the same plot for 50 years have previously been mentioned. For the sake of comparison the table gives the averages for the same eight years in which these crops were grown in rotation All the crops were harvested and removed from the field, and as no manure of any kind was used it will be seen that the increased production of barley and wheat is a result of rotation solely. No stronger argument in favor of rotation of crops is necessary.

Planning a Rotation.—Rotations are in use that cover periods of from two to seven years. In planning a rotation the farmer must be guided by his own conditions and requirements in the way of crops. A few general rules may be laid down, however. Every rotation should include at least one cultivated or hoed crop, such as corn, potatoes, etc., in order to receive the benefits of such a crop in the way of destroying weeds, improving tilth and setting free potential plant food. At least one leguminous crop should be included. The legumes are generally deep rooted crops, and in addition to increasing the nitrogen supply of the soil, bring up plant food from the subsoil and leave it where it will be available to the succeeding crop. These deep rooted plants render the subsoil more porous and hasten its disintegration. A crop that is exacting in its food requirements should follow one that is less exacting, or in general terms, the crops should vary as much as possible in their food requirements, manner of growth, root system and the season of the year in which they occupy the ground. Whatever fertilizers are used

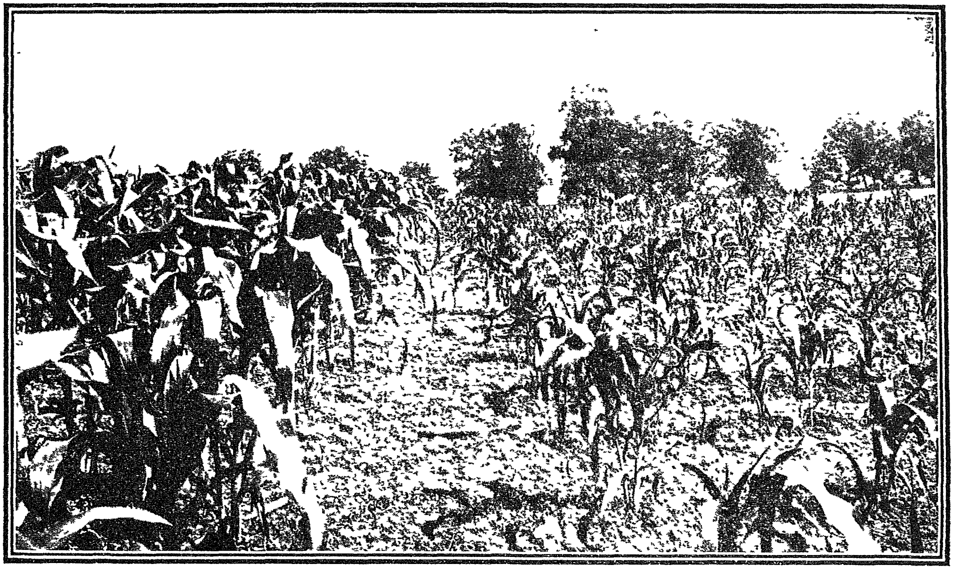
should be applied to the particular crop which will give the most profitable returns for their use.

Résumé.—In Part I the reader was reminded that continuous cropping without the use of fertilizers finally results in practical exhaustion of the soil. The food of the plant, and the history of the formation of the soil were briefly considered, and the conclusion was evolved that to maintain the fertility of the land two things were necessary; first, to make more of the potential food available; second, to add something to take the place of the materials removed in the crop.

Part II has been devoted to a discussion of the first proposition. Tillage, drainage, irrigation, fallowing, green manuring and rotation are distinctly methods of changing potential plant food into available forms and, with the exception of the nitrogen gathered by the legumes, add no plant food whatever to the soil. Although, as has been previously stated, it is claimed by some that by an intelligent use of these processes alone a profitable yield can be obtained indefinitely, it is the common experience that even with the use of the best methods of culture known in the past, it is impossible to maintain the fertility of the land without the use of some form of fertilizers. As it is obviously impossible to return the crop to the soil, the next thing that suggests itself is to feed the crop to the farm animals and use their excrement as a fertilizer. The subject of barnyard manures is of sufficient importance to justify its discussion at some length as Part III of this treatise.

PART III

BARNYARD MANURE



Effect of stable manure on growth of corn. The plot on the left was manured with stable manure, while the one on the right received none. Stable manure is the best and safest of all fertilizers

CHAPTER XI

FACTORS AFFECTING THE VALUE OF FRESH MANURE

Importance of Barnyard Manure.—Barnyard manure is the oldest and is still undoubtedly the most popular of all fertilizers. It has stood the test of long experience, and has proven its position as one of the most important manures. The fact that the application of the excrement of animals to the soil results in increased crop production, is mentioned by the early Roman writers, and from that time to the present, the majority of farmers have placed their main reliance on this class of manures for maintaining the fertility of the land.

"A well kept manure heap may be safely taken as one of the surest indications of thrift and success in farming. Neglect of this resource causes losses which, though little appreciated, are vast in extent. Waste of manure is either so common as to breed indifference, or so silent as to escape notice.

"According to recent statistics there are in the United States in round numbers, 19,500,000 horses, mules, etc., 61,000,000 cattle, 47,000,000 hogs, and 51,600,000 sheep. Experiments indicate that if these animals were kept in stalls or pens throughout the year and the manure carefully saved, the approximate value of the fertilizing constituents of the manure produced by each horse or mule annually would be $27, by each

head of cattle $20, by each hog $8 and by each sheep $2. The fertilizing value of the manure produced by the different classes of farm animals of the United States would, therefore, be for horses, mules, etc., $526,500,000; cattle $1,220,000,000; hogs $376,000,000; and sheep $103,200,000 or a total of $2,225,700,000.

"These estimates are based on the values usually assigned to phosphoric acid, potash and nitrogen in commercial fertilizers, and are possibly somewhat too high from a practical standpoint. On the other hand, it must be borne in mind that no account is taken of the value of manure for improving the mechanical condition and drainage of soils, which as subsequent pages will show, is fully as important a consideration as its direct fertilizing value." (Farmers' Bulletin 192).

If it is assumed that one-third of the value of the manure is annually lost by careless methods of management, and this estimate is undoubtedly conservative, the total loss from this source in the United States is about $750,900,000; a loss the more unfortunate because practically all of it could be prevented.

Composition of Manure From Different Animals.—The manures produced by the various classes of animals differ greatly in their composition and in their physical properties. The table on the next page gives the average percentage composition of the fresh manures (including solid and liquid excrement) from the more common farm animals.

By reference to this table it is seen that the difference in the value of the manures as given is due, to a large extent, to the variation in the amount of water present in the excrement of the different classes of animals.

AVERAGE COMPOSITION OF FRESH MANURES (WOLFF)

	Water per cent	*Nitrogen per cent.*	*Phos acid per cent.*	*Potash per cent.*	*Value per ton**
Sheep	64 0	0 83	0 23	0 67	$3 39
Horse	70 0	0 58	0 28	0 53	2 55
Pig	73.0	0 45	0 19	0 60	2.14
Cow	77 0	0 44	0 16	0 40	1.89
Mixed	75 9	0.45	0 21	0 52	2 08

The moisture content also affects the physical properties of the manure. Manures containing large amounts of water are "cold manures"; that is they are manures which heat slowly because the amount of moisture present checks the fermentation. Sheep and horse manures are known as "hot manures," and the more rapid heating of these when compared with pig or cow manure is probably due to their lower water content. The difference in the kind and quality of the feeds given to the various animals also affects the quality of the manure, as will be shown later.

Amount and Value of Manure From Different Animals.—The figures given in the previous section show the comparative fertilizing value of the different animal excrements and are, therefore, of importance to one who is purchasing manures. For the farmer who

* This valuation is based on 15 cents per pound for nitrogen, and 5 cents for phosphoric acid and potash This represents in round numbers the market price of these elements in commercial fertilizers at the present time. All the valuations given in the following pages will be on the same basis.

produces manure to use on his own land, it is more important to know the total amount and value of the manure produced in a year by the different classes of animals. In the quotation above from Farmers' Bulletin 192 the approximate value of the manure produced per head by the ordinary farm animals is given. A fairer way to present the matter is to calculate the manure to the same live weight of the different animals. The following table compiled from Cornell Bulletin 56 appears in Farmers' Bulletin 192.

AMOUNT AND VALUE OF MANURE PER 1,000 POUNDS OF LIVE WEIGHT OF DIFFERENT ANIMALS

	Amount per day pounds	*Value per day cents*	*Value per year dollars*
Sheep	34 1	7 2	26.09
Calves	67.8	6.7	24.45
Hogs	56.2	10.4	37 96
Cows	74.1	8 0	29.27
Horse	48 8	7.6	27.74

If the figures given in this table are accepted as representing normal conditions, it follows that, making proper allowance for the proportion of the different kinds of animals found on the ordinary farm, the sum of thirty dollars may be taken as the average value of the fresh manure from each 1,000 pounds of live weight. The use of this factor (thirty dollars per 1,000 pounds) will enable the farmer to calculate approximately what the nitrogen, phosphoric acid and potash in the manure produced on his farm would cost if purchased in commercial fertilizers, granting

that the manure is so managed as to prevent loss of its valuable constituents.

Value of the Manure Determined by the Ration.—The total value of the manure produced by a given number of animals is dependent on the quality and quantity of the feeding stuff used in the ration. That the different materials used for feeding vary greatly in their fertilizing value is clearly shown in the following table, which gives the quantity of fertilizing materials in one ton of a few of the common feeding stuffs.

	Nitrogen pounds	*Phos acid pounds*	*Potash pounds*	*Value per ton*
Corn meal	36 4	14 0	8 0	$ 6 56
Corn silage	5 6	2 2	7.4	1 32
Corn stover	20 8	5 8	28 0	5 81
Clover hay	41 4	7 6	44.0	8 79
Gluten meal	100 6	6.6	1 0	15 44
Linseed meal	108 6	33 2	27 4	19 22
Cotton-seed meal	135 8	57 6	17.4	23 20
Meat scraps	194.0	126 0	14.0	36 10
Oats	41.2	16.4	12.4	7 62
Timothy hay	25.2	10 6	18.0	5.21
Wheat bran	53.4	57 8	32.2	12.52
Wheat straw	11.8	2.4	10.2	2 40

The figures given in the above table represent the fertilizing values of the different feeds, provided they are used directly as manures. It is evident that the

richer the ration is in nitrogen, phosphoric acid and potash, the more valuable will be the manure produced by the animal. The next question to determine is what proportion of the fertilizing content of the food is recovered in the excrement.

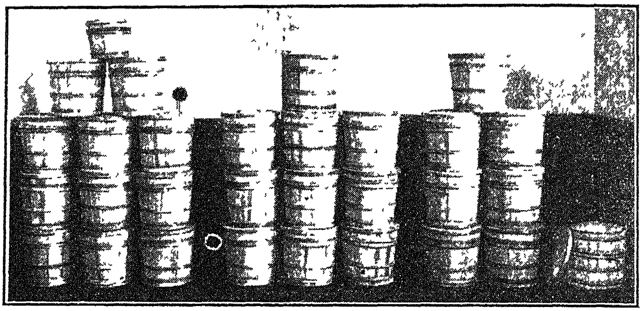
No Loss of Plant Food With Mature Animals.—Let the reader imagine that a matured animal (a steer for instance) is confined in such a manner that all of the excrement, both liquid and solid, can be preserved, and that the animal is kept on a maintenance ration. If now the total dry matter in the materials fed is determined, and likewise that voided in the excrement, it will be found that the dry matter in the excrement is just about one-half the amount that was present in the food consumed, the greater part of the other half having been given off from the lungs as carbonic acid gas If, on the other hand, the food is analyzed to determine the nitrogen, phosphoric acid and potash it contains, and the excreta are also examined, in the same way, it will be found that the entire amount of these constituents is voided by the animal in the solid and liquid excrement. While the excreta, therefore, contain only half of the total dry matter which was present in the ration, they contain all the constituents that are generally considered to have fertilizing value.

Young Animals Retain Part of Plant Food.—While these figures would hold good for a matured steer that was neither gaining nor losing in weight, they are not correct for young and growing animals The latter retain a certain proportion of the nitrogen and phosphoric acid for use in building up their bodies. The amount thus retained depends primarily on the

age of the animal, and also as will readily be imagined, on the rapidity of its growth. Recent experiments indicate that calves during the first three months of their lives retain in their bodies about one-third of the fertilizing value of the food consumed, or in other words, the excrements from such animals contain two-thirds of the fertilizing ingredients of the ration. For the first year of their existence they use in body growth an average of about one-fifth of the nitrogen, phosphoric acid and potash that was present in the food, and the amount gradually diminishes until practically not any of these materials are retained. It may be noted here that where matured animals are gaining in weight during fattening there is no drain on the fertilizing value of the manure, provided the gain in weight is all in fat. This is due to the fact that fat contains only carbon, hydrogen and oxygen, and hence its production does not remove any of those constituents which are considered in calculating the fertilizing value. Although the steer and calf have been used by way of illustration, the remarks regarding them hold true as well of the other classes of animals such as swine, sheep and horses, and the age of the animal has the same effect on the value of the manure.

The Milk Contains Some Plant Food.—In the case of the cow another factor is introduced, as a certain proportion of the nitrogen, phosphoric acid and potash is removed in the milk. Milk contains on an average about 0.53 per cent of nitrogen, 0.19 per cent of phosphoric acid and 0.175 per cent of potash. A cow giving an annual yield of five thousand pounds, therefore, removes in the milk fertilizing materials amounting in

value to $4.89. If the milk is sold this amount of fertility is removed from the farm. If, on the other hand, butter only is sold practically none is carried away, as all the valuable ingredients are found in skim-milk; the fertilizing value of three hundred pounds



Butter removes a smaller quantity of the elements of fertility than any other product which is sold from the farm. The fertilizing value of one ton of butter amounts to only 44 cents

of butter, for instance, amounting to only 6½ cents. Even where the milk is removed fully 85 per cent of the manurial value of the food is recovered.

Eighty Per Cent of the Plant Food Recovered in Manure.—It will thus be seen that a very large part of the elements of fertility contained in the ration fed is recovered in the excreta, and that the age of the animal is the principal factor in determining the amount that is removed. The fertility removed in the milk when it is sold from the farm is also of considerable importance, and should not be ignored. Taking into account the relation between matured and young stock, milch cows and non-milk producing animals, as found on the average farm, it is conservative to assume

that at least 80 per cent of the nitrogen, phosphoric acid and potash, present in the materials fed on the farm, is voided by the animals in the solid and liquid excrement. This takes into consideration the amount removed in the milk, that retained by the young animals during their growing period, and, consequently, the fertility removed from the farm by the sale of the animals produced thereon. In order, then, to determine the fertilizing value of the excrement produced from a ton of any of the feeding stuffs mentioned in the table given above it is only necessary to find eighty per cent of the fertilizing value therein stated. It will thus readily be seen that the composition of the feeding stuff really determines the value of the excrement. That produced from one ton of wheat straw being worth only $1.74, while the excrement from one ton of corn meal, wheat bran, linseed meal or cottonseed meal would be worth $4.53, $9.84, $15.49 and $20.93 respectively.

Nitrogen the Most Valuable Constituent of Manure.—By referring to the table it is seen that the most important factor in determining the fertilizing value of a feeding stuff, or the manure produced from it, is the amount of nitrogen that it contains. This is due to the fact that nitrogen is usually present in larger proportion than phosphoric acid or potash, and is much more costly when purchased. Nitrogen is also used by the animal body in much larger amounts than the other substances, and the difference in fertilizing value between the food and the excrement is largely due to the retention of nitrogen. It will be shown that the

tent than on the other elements, so it again becomes evident that the most expensive material to furnish is also the one most readily lost. This but confirms a previous statement that the problem of the profitable maintenance of fertility is largely a question of an economic method of supplying the plant with nitrogen.

Effect of Ration on Value of Manure Per Ton.—While the total value of the excrement depends almost entirely on the composition of the ration, it does not follow that the value of the manure per ton is proportional to the fertilizing value of the substances fed. Cattle fed on highly nitrogenous rations drink more water than those kept on a ration low in nitrogen, and experiments have shown that the excrement contains a larger per cent of water in the former case than in the latter. The cattle fed on the narrow ration will produce more tons of excrement at a greater total value, but the value per ton will not be very different from that resulting from a wider ration. The following table adapted from a Cornell bulletin gives results with two lots of pigs, Lot I, having been kept on feeds extremely high in nitrogen, while Lot II, were given a ration containing a much smaller proportion of nitrogenous materials.

EXCREMENT FROM 1,000 POUNDS LIVE WEIGHT OF PIGS

	Weight per day, lbs.	*Value per day*	*Value per ton*
Lot I	108.9	$0.2106	$3 86
Lot II	56 2	0.104	3.66

It is noteworthy that while the total value of the manure produced per 1,000 pounds of live animal in

Lot I was twice that of Lot II, there is very little difference in the value per ton, due to the fact that the weight of excrement produced in the first case was nearly twice that in the latter.

Effect of Bedding on Value of Manure.—The factors just discussed are those which affect the value of the excrement. The term barnyard manure as it is generally used includes the excreta and the litter or bedding used to absorb the urine. The following table gives the composition of some of the materials used for bedding.

FERTILIZING CONSTITUENTS IN ONE TON OF LITTER

	Nitrogen pounds	*Phos. acid pounds*	*Potash pounds*
Wheat straw	9.6	4.4	12.6
Oat straw	9.2	5.6	35.4
Clover straw	29.4	8.4	25.2
Sawdust	4.0	6.0	14.0
Peat	20.0	...	...

It is evident that the total fertilizing value of the manure is the sum of the value of the excrement and the bedding, and the richer the bedding is in fertilizing constituents the more valuable will be the manure. The materials used for bedding are in most cases rather low in the elements of fertility so that the use of large amounts of bedding decreases the worth per ton of the manure, but in any case sufficient litter should be used to absorb all of the liquid excrement.

Calculating the Amount of Manure From the Ration.—It is often of great interest and importance to the farmer to be able to calculate approximately the

amount of manure that will be produced from the materials fed to his animals, as well as its value. Various estimates of the amount of manure produced by the different classes of animals have been made from time to time, but it will be much more satisfactory to use the ration as a basis for calculation. The total weight of manure may easily be computed in this way

A way in which plant food is often wasted. If the straw is not used for feed or bedding it should at least be scattered

and the figures derived are remarkably close to the average results as determined by experiment.

It has been stated that 50 per cent of the dry matter present in the ration is recovered in the excrement. Experience has shown that the least amount of bedding that will absorb all of the urine excreted by the animal must contain dry matter equal to 25 per cent of the dry matter in the feeding stuffs used. Hence, if the assumption is made that just sufficient bedding is used

to absorb all of the liquid excrement it is seen that the manure (excrement plus bedding) contains 75 per cent as much dry matter as was contained in the ration. According to the table on page 115, mixed farm manures contain on the average 75 per cent of water, or only 25 per cent of dry matter, so that the 75 per cent of dry matter mentioned above as occurring in the manure, must be multiplied by four to find the total of manure This gives a result of 300 per cent of the dry matter in the ration for the weight of the manure produced therefrom. It will thus be seen that to calculate the amount of manure resulting from the use of any given food materials it is only necessary to multiply the weight of the dry matter in the ration by three. This method of computation may perhaps be made plainer by an example. Let it be assumed that a mixture of feeding stuffs is used which contains 1,200 pounds of dry matter. The excrement produced by feeding this ration would contain 600 pounds of dry matter. In order to absorb all of the urine voided by the animal, straw, or some other bedding material must be used in an amount large enough to supply 300 pounds of dry matter. Now, as the manure is composed of the excrement plus the bedding it follows that the manure contains 900 pounds of dry matter. Only 25 per cent. of the manure is dry matter, so that the 900 pounds of dry matter in the example represents one-fourth of the total weight of the manure. The manure, therefore, weighs 3,600 pounds, which is just three times the dry matter that was present in the ration assumed.

This method of calculating the manure by multiply-

ing the dry matter in the ration by three holds true, of course, only when the theoretical amount of bedding is used. In actual practice the farmer uses all of the bedding materials he has at hand even though in excess of the amount required to absorb the urine, and it is generally considered advisable to do so, for the bedding materials decay much more readily when mixed with the excrement of animals. In the best farm practice where the greatest possible use is made of all substances suitable for feeding there is seldom an excess of bedding materials. In case more litter than the theoretical amount is used the method of calculation given above must be corrected by adding to the total, the weight of the bedding in excess of 25 per cent of the dry matter in the ration. If in the example, for instance, instead of using 300 pounds of straw 500 pounds had been used as bedding, the total weight of the manure would have been 3,800 pounds.

CHAPTER XII

AMOUNT AND VALUE OF THE MANURE PRODUCED ON A FARM

Value of Manure Little Appreciated.—The great value of barnyard manure as a farm resource is appreciated by very few farmers. Its importance is doubtless realized to a greater extent at the present time than ever before, but even now a large proportion of those engaged in agricultural pursuits seem to have little realization of the immense loss incurred through the waste of this important product of the farm. Indeed many farmers apparently look upon the manure as one of the necessary nuisances of a system of animal husbandry, and begrudge the time and labor required to remove it from the barn and feeding lot. Barns have been erected on the banks of swift running streams with the express purpose of emptying the manure into the creek, in order that it may be removed with the least possible expenditure of labor. While these cases are extreme the reader has only to look around him as he travels through the country to see practices which fall only a few degrees short of this in the matter of wastefulness, due either to lack of knowledge of the value of the manure or to an indifference that is even more lamentable than ignorance.

Manure From Fifty Cows.—In order that the great fertilizing value of the manure produced on the farm may be more definitely shown as well as to make more

clear the methods of calculation described in the previous chapter, figures are given here for the food consumed and the amount and value of the manure produced in one year by a herd of 50 dairy cows, giving an average yield of 15 pounds of milk daily. For the sake of simplifying the calculations and statements of results it is assumed that the same ration is fed throughout the year. In actual practice, of course, the ration varies somewhat at different times of the year, but as the experienced feeder aims to keep approximately the same relation between the concentrates and roughage, and, as nearly as may be, the same ratio between proteids and carbohydrates, the results of this computation from a single ration will not be very different from those which would be derived from a variety, each having about the same nutritive value.

The Ration Used.—It is desired to make this estimate conservative and for this reason no feeds are included that are unusually high in fertilizing constituents. The following ration will be used as a basis for the calculation:

Daily ration for a cow weighing 1,000 pounds and giving 15 pounds of milk per day; 10 pounds of a mixture of one-third each of cornmeal, ground oats, and bran; 35 pounds of corn silage; 15 pounds of clover hay (medium red).

This combination has been recommended by a prominent authority on the feeding of animals as a good ration for practical feeding, and one which will meet with the approval of conservative dairymen. At the same time the ration is well balanced, and will conform reasonably well to the best feeding standards. A

great many people use a higher feeding standard than is represented by this ration so on the whole it may be said that the results of this calculation certainly are not higher than the average for good dairy conditions. It will be assumed that just the amount of wheat straw which would theoretically be necessary to absorb the liquid excrement is used as bedding.

The following table gives the dry matter and fertilizing constituents in each 1,000 pounds of the different materials.

DRY MATTER AND FERTILIZING CONSTITUENTS IN 1,000 POUNDS

	Dry matter pounds	*Nitrogen pounds*	*Phos acid pounds*	*Potash pounds*
Cornmeal	871	15 8	6 3	4 0
Oats	889	18 6	7 7	5 9
Bran	883	26 7	28 9	16 1
Silage	220	2 8	1 1	3 7
Clover	887	20 7	3 8	22 0
Straw	875	4 8	2 2	6 3

Fertility in the Excrement.—The ration mentioned above represents the amount of the different substances fed to each cow per day. This amount must be multiplied by 50 and then by 365 to determine the total amount fed per year. From the totals thus obtained and by the use of the table just given it is possible to calculate the dry matter and fertilizing con-

stituents of the entire amount of food given to the fifty cows during the year. These results are compiled in the following table.

TABLE SHOWING TOTAL AMOUNT OF MATERIALS FED WITH DRY MATTER AND FERTILIZING CONSTITUENTS

	Amount fed pounds	*Dry matter* pounds	*Nitrogen* pounds	*Phos acid* pounds	*Potash* pounds
Cornmeal	60,830	52,982 9	967.11	383 23	243.32
Oats	60,830	54,077.8	1,141.34	468 39	358.90
Bran	60,830	53,712.9	1,624.16	1,757.98	979.36
Silage	638,750	140,525.0	1,788.50	702.63	2,363.38
Clover	274,250	239,968 7	5,676.88	1,042.15	6,033.50
Totals	1,095,490	541,267 3	11,197.99	4,354.38	9,978.46

While the totals given in the table show the amounts of fertilizing constituents in the feeding stuffs used during the year it will be remembered that only eighty per cent of this amount is recovered in the excrement The solid and liquid excrement combined, therefore, contain of nitrogen 8958.47 pounds, phosphoric acid 3483.50 pounds and potash 7982.77 pounds.

Fertility in Bedding Must be Added.—The manure, however, contains the fertilizing constituents of the bedding in addition to that found in the excrement. It has been stated that the least amount of bedding that will absorb the urine must contain dry matter equivalent to one-fourth the dry matter in the ration.

The dry matter in the bedding used in this example, therefore, must amount to 135,316.8 pounds. To furnish this quantity of dry matter it is necessary to use at least 154,647.7 pounds of wheat straw. If the amount of nitrogen, phosphoric acid and potash in this weight of straw are added to that in the excrement the results will express the quantities of these ingredients found in the manure. The following table gives these data:

FERTILIZING CONSTITUENTS OF THE MANURE

	Nitrogen pounds	*Phos acid pounds*	*Potash pounds*
In excrement . .	8958 47	3483 50	7982 77
In bedding . . .	742 61	340 22	974 28
Totals . . .	9701.08	3823.72	8957.05

Value of the Manure.—The prevailing prices of fertilizing materials at the present time as given by the eastern experiment stations are such that the purchaser pays at the rate of about 15 cents per pound for nitrogen, and 5 cents each for phosphoric acid and potash. These prices hold only when crude materials are bought and much higher prices are paid for mixed fertilizers. To determine the value of the manure produced by the 50 cows it is only necessary to multiply the totals in the last table by the trade prices of the constituents. These calculations are given below:

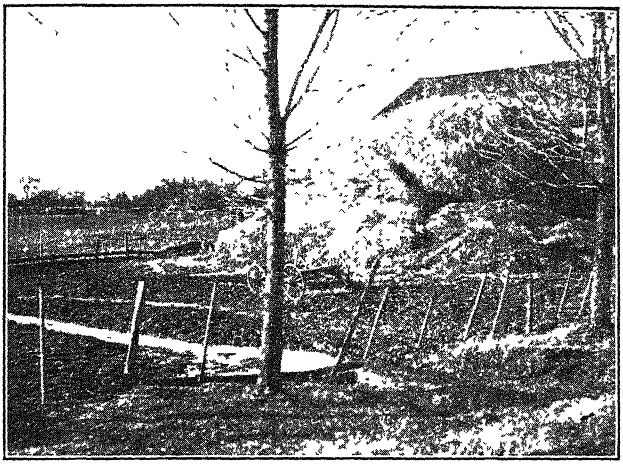
VALUE OF MANURE FROM 50 COWS

Value of nitrogen	$1,455.18
Value of phosphoric acid	191 19
Value of potash	447.85
Total value of manure	2,094.22

This means that the fresh manure from the 50 cows contains amounts of nitrogen, phosphoric acid and potash that would cost the farmer at least $2,094.22 if purchased in commercial fertilizers. How nearly the actual agricultural value of the manure will approach the trade value depends upon a number of conditions such as the crop to be fed, the physical condition and tilth of the soil, the climatic conditions and above all the intelligence displayed in its care and use. The same statements apply to commercial fertilizers, the trade price not necessarily being any indication of the agricultural value of the material, and there is no doubt that the farmer who receives the best returns from commercial fertilizers is also the one who will be best repaid for the use of barnyard manure. Whatever the reader's opinion may be of the actual value of manure, the figures evolved in this calculation must impress him with the fact that his manure heap is a valuable resource, and that he cannot afford to waste so valuable a substance even if it is but a by-product of the farm.

Amount of Manure and Value Per Ton.—It will be interesting to carry these calculations a little further and determine the total amount of manure produced and the value per ton. It has been shown that the weight of the manure is three times the weight of the dry matter in the ration. The total dry matter fed during the year was found to be 541,267.3 pounds so the manure would weigh 1,623,801.9 pounds or 811.9 tons. The total value of the manure divided by the number of tons gives $2.58 as the value of a ton of the manure. In this connection it is interesting to

note that in field experiments conducted for ten years at the Ohio Experiment Station, the average value of the increase of crop produced by one ton of fresh manure amounted to $3.44. If 50 cents per ton is allowed as the cost of applying the manure to the field there



A very wasteful method of handling a valuable product Such a barnyard must result in great loss of fertility

still remains a handsome profit as a result of the application.

A Profitable Calculation.—The easiest way for the farmer to calculate the value of the manure produced per year on his farm is to add together the amounts of fertilizing constituents in all the feeds fed to the various animals, take 80 per cent of this, and add to it the fertilizing constituents of the bedding, and multiply the totals by the trade prices per pound for nitro-

gen, phosphoric acid and potash. If the reader will take the trouble to do this for his own farm, using the table at the back of this book to find the fertilizing constituents in his crops, he will find the results extremely interesting, and will be well repaid for his labor, in the better understanding that he will have of his farm resources.

How to Increase the Value of the Manure.—It often occurs that the farmer finds it necessary for one reason or another to supply more plant food to the soil than can be obtained from the manure produced from the crops raised on his farm. Under these circumstances, if he is engaged in animal husbandry, he will find that the most economical way to increase the plant food is by purchasing feeding stuffs rich in the fertilizing constituents, feeding them to his animals and using the manure as a fertilizer. The most successful stockmen find it profitable to reinforce the feeds raised on the farm with one or more of the various mill and other by-products that are sold as cattle feeds. A glance at the table on page 117 will immediately suggest how easily the value of the manure might be increased at the same time that the ration was being materially improved. It will readily be seen that the purchase of a relatively small quantity of some of the concentrated feeding stuffs would more than replace the 20 per cent of fertilizing value of the crops lost during feeding. The farmer who buys large quantities of concentrates is increasing the fertility of his land provided he is taking proper care of the manure. In purchasing feeding stuffs one should always consider their fertilizing value as well as the feeding value.

for, while the substance is bought primarily to feed, it is sometimes possible to buy two different materials which will serve practically the same use as feeds, and yet vary greatly in their values as fertilizers. Even where a number of animals sufficient to consume all of the crops raised on the farm is at hand it is often advisable to sell some of the products, and use the money thus obtained for the purchase of other feeding stuffs. There is scarcely a farm on which such an exchange could not be made to advantage, both from the feeding standpoint, and in order to increase the value of the manure. A study of the market prices of the various farm products and concentrates in any year will readily show how such exchanges could be made at a profit to the farmer. To illustrate what is meant by this statement the following simple example recently used by the writer in one of his classes is given.

At the time mentioned it was possible to buy on the local market seven tons of clover hay for the price of five tons of timothy hay, and five tons of corn could have been exchanged for six tons of bran. The problem was to determine the increase in fertilizing value due to such an exchange. Calculating the value of the different materials in the manner already described the results may be briefly stated as follows:

Fertilizing value of 7 tons of clover	$52.85
Fertilizing value of 6 tons of bran	73 80
Total	$126 65
Fertilizing value of 5 tons of timothy	$23.00
Fertilizing value of 5 tons of corn	28.30
Total	$51.30
Gain due to exchange	$75.35

By a simple exchange of products without any cash outlay the fertilizing value of the ration would have been increased $75.35, and consequently the manure produced would have been worth $60.28 more than that resulting from the use of the corn and timothy hay. The increase in value of the manure does not tell all of the story, for the total weight of food has been increased nearly one-third. Its actual feeding value has been increased more than one-third, due to the larger amount of proteid in the ration It is well known that cattle require less weight per head of a narrow ration than of one that is more carbonaceous. This example is cited merely as a suggestion of the possibilities of exchange. A little careful consideration will show that such exchanges may be made of great practical value.

The value of manure is affected by the quantity of food given the animal as well as by the quality. Other things being equal the manure from animals fed liberally will be more valuable than that from those that are fed insufficiently. This is mainly due to the fact that the latter use a larger proportion of the nitrogen of the food and hence the percentage returned in the manure is smaller. Liberal feeding then produces richer manure.

CHAPTER XIII

LOSSES IN MANURE

Relative Value of Solid and Liquid Excrement.— The great possibilities of barnyard manure as a means of supplying nitrogen, phosphoric acid, and potash to the soil have been discussed at some length. While values equal to those mentioned may be realized by any farmer by the exercise of reasonable care, the fact remains that few even approximate these results with their present practices. Barnyard manure is a perishable material, and must be handled with care and intelligence to obtain its maximum value. As manure is handled on the majority of farms to-day it is doubtful if half its worth is realized. The greatest loss that is likely to occur is the waste of the liquid excrement through the use of insufficient bedding to absorb it. The urine is really the most valuable part of the excrement, and unless plenty of bedding is used the value of the manure will fall far below that given in the previous chapter. Apparently few people realize the importance of using plenty of litter, for it is not unusual to see barns constructed in such a way as to cause the urine to run off as rapidly as possible. Doubtless the reader has before now seen holes bored in the barn floor to keep the floor dry by draining off the liquid excrement. The following table gives the composition of the solid and liquid excrements:

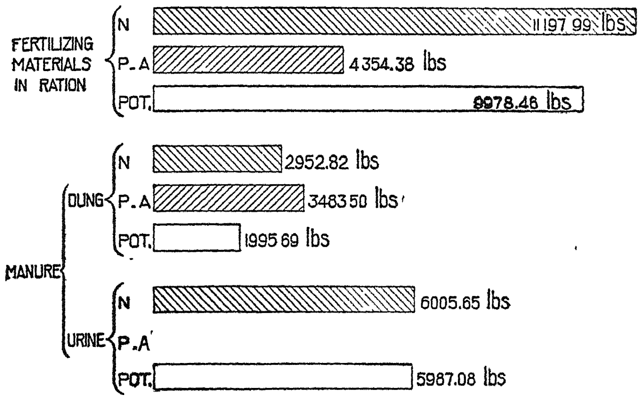
PERCENTAGE OF FERTILIZING CONSTITUENTS IN SOLID AND LIQUID EXCREMENTS

	Nitrogen		*Phos. acid*		*Soda and Potash*	
	Solid	*Liquid*	*Solid*	*Liquid*	*Solid*	*Liquid*
Horses	0.50	1 20	0 35	trace	0 30	1.50
Cows	0 30	0 80	0 25	trace	0 10	1.40
Swine	0 60	0 30	0.45	0 125	0 50	0 2
Sheep	0.75	1 40	0 60	0.05	0 30	2.0

The table shows that considered pound for pound the liquid excrement is more valuable than the solid, except in the case of the swine. As the relative weights of solid and liquid excrement produced by the animals are not given it does not show the real proportional value of the liquid and solid excrement produced from a given ration. Several experiments have been made to determine this point, and there is a wide variation in the results. It is perfectly safe to say, however, that of the total fertilizing materials found in the manure two-thirds of the nitrogen, and four-fifths of the potash are found in the urine, but practically none of the phosphoric acid. The solid part then contains only one-third of the nitrogen, one-fifth of the potash, and nearly all of the phosphoric acid. It will thus be seen that a little over half of the total value of the manure is in the urine. In the example mentioned in Chapter XII, if the liquid excrement had been allowed to run away the value of the manure would have been less than $900.00 instead of $2,094 00 as calculated.

This fact is presented graphically in the diagram which shows the distribution of the fertilizing ingredients in the manure produced from the assumed ration

DIAGRAM SHOWING DISTRIBUTION OF FERTILIZING INGREDIENTS IN MANURE



Value of the dung	$ 716 88
Value of the urine	1,200.20
Value of the bedding	177.12
Total value of manure	$2,094 20

Plant Food in Liquid Excrement More Available.—The above statement does not properly show the comparative value of the solid and liquid parts of the manure. The plant food in the urine is in a form that is soluble in water, and, consequently, much more readily available to the plants than that in the solid excrement. The solid excrement consists of the undigested portion of the food, and must undergo thorough decay before its fertilizing constituents become avail-

able to the plants, so that while something more than half of the actual plant food is in the urine, the value of the urine is much greater than the dung, owing to the better condition of its plant food. The difference is due largely to the more available form in which the nitrogen exists in the urine.

That the difference in value of solid and liquid excrement is not wholly theoretical is shown very nicely by a New Jersey experiment. In this experiment two plots were treated with manure, in one case the solid excrement only was used, in the other the mixed solid and liquid excrement. Each plot received enough of the manure to supply exactly the same amount of nitrogen, and the other elements were added in excess. The results are stated in percentage of gain over a check plot that received no manure and are given below.

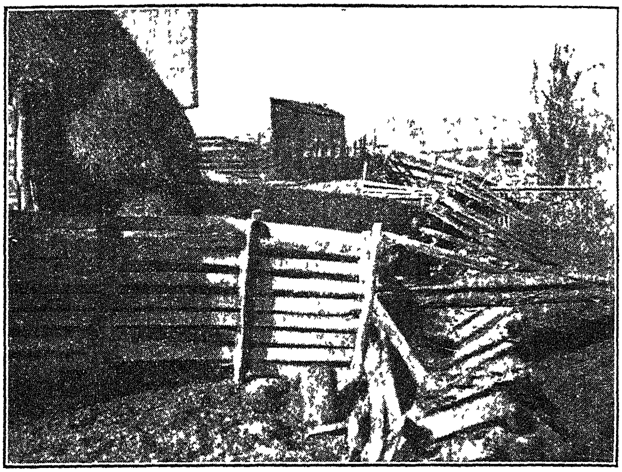
PERCENTAGE OF GAIN IN YIELD FROM MANURE

	Solid excrement only	*Solid & liquid excrement*
First year	15.2	52.7
Second year	69.7	116.9
Third year	47.9	80.6
Average	44.3	83.4

It will be seen that the yield from the same amount of nitrogen was very much larger from the mixed manure than from the solid excrement alone. As the total amount of nitrogen added was the same in each case, the experiment indicates that the nitrogen in the liquid excrement was much more readily utilized by the plant than was that in the solid excrement.

Manure is never so valuable as when perfectly fresh.

The very best methods of handling and care, if the manure is stored, cannot prevent more or less loss of the valuable constituents. For this reason it is advisable when possible to apply the manure to the soil as



The small stream in the foreground is highly colored by the leachings from the pile of manure against the barn. The best part of the manure is being lost

fast as it is made, a point that will be discussed at some length later.

Losses in Manure From Leaching.—Next to improper absorption of the urine, the greatest loss in manure comes from leaching by rains. As ordinarily handled the manure is thrown out each day into the open yard to lie for months subject to washing by the summer or winter rains. In many cases it is even deposited under the eaves of a large barn so as to make the washing process more complete. It seems

absurd to go to the trouble of absorbing all the liquid excrement by means of bedding, and then to allow it to be washed out of the manure by the rains, and yet that is what very often occurs. The losses in manures due to leaching by rains in the open yard are much greater than most people imagine. Many experiments have been carried on to illustrate these losses.

At the New Jersey Experiment Station four samples of manures were exposed to the weather for varying periods and the loss of fertilizing constituents determined. The results are summarized in the following table:

LOSSES IN MANURE FROM LEACHING

Period *Days*	*Nitrogen* *per cent*	*Phosphoric acid* *per cent*	*Potash* *per cent*
131	57.0	62 0	72.0
70	44 0	16.0	28.0
76	39 0	63 0	56 0
50	69 0	59.0	72 0
Average	51 0	51 1	61 1

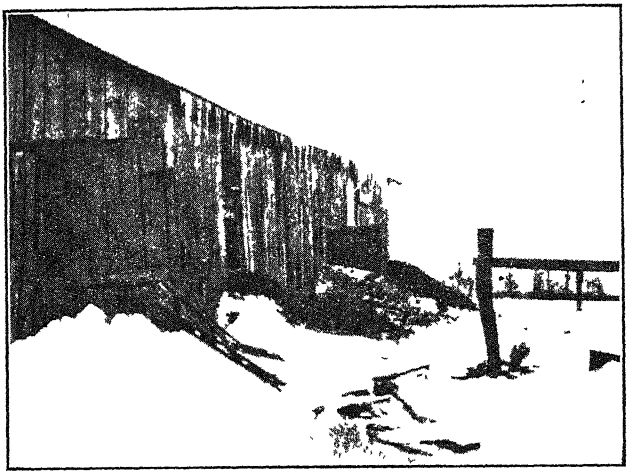
It will be seen that the average loss amounted to more than half of the value of the manure during rather short periods, the longest time being a trifle over four months. On many farms the manure is exposed to the elements for a much longer period than that given in the table.

In 1890 experiments were conducted at Cornell University Experimental Station, with manure exposed to

the weather for a period of five months (from April to September) with the following results:

	Value at beginning per ton	*Loss per ton*	*Loss per cent.*
Horse manure . . .	$2.80	$1.74	62.0
Cow manure	2.29	.69	30.0

Tests at the Central Experimental Farm at Ottawa, Canada, with horse manure exposed to the weather

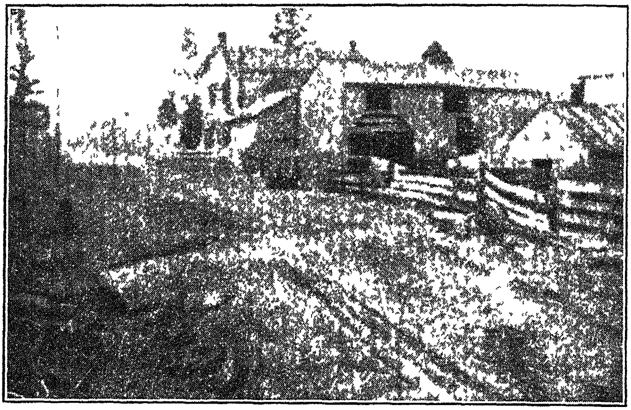


Comment is unnecessary

for six months showed a loss of one-third of the nitrogen, one-sixth of the phosphoric acid and one-third of the potash, while a corresponding sample that was protected from the weather lost only one-fifth of its nitrogen, and none of the phosphoric acid or potash

Examples similar to these might be given indefinitely from American and European experiments, but it is

only necessary here to state that all of these experiments show great losses in the valuable constituents of the manure from exposure to the elements, the decrease in value amounting to from thirty to seventy per cent for periods of from three to twelve months. These losses vary with the climatic conditions and with the quality of the rations. During heavy rains, espe-



The culvert across the road was built to keep the barnyard dry. The colored stream which runs through it tells a story of waste of plant food

cially if occurring in warm weather, the losses will be much greater than in dry or cold weather. The relative decrease in value is larger for manures produced from rations of high nutritive value In other words the more valuable the manure the greater will be the percentage of loss from leaching. It is conservative to say that manure exposed to the weather for six months loses fully half its value.

Solid Excrement Loses Value by Leaching.—It is not the liquid excrement alone that is washed away by

the rains, for the solid excrement contains a certain amount of soluble plant food which is removed by leaching. In addition to this there are chemical changes taking place in the manure which are converting some of the constituents, which were originally insoluble, into forms that are soluble in water, and these may be carried away by the rains Below are given the results of experiments at the New Jersey Experiment Station to determine the losses due to leaching when the solid excrement alone was considered

LOSSES IN SOLID EXCREMENT FROM LEACHING

Period Days	*Nitrogen* per cent	*Phosphoric acid* per cent	*Potash* per cent
131	46 0	72 0	80 0
70	34 0	27 0	10 0
76	25 0	54 0	48 0
50	45 0	42 0	42 0
Average	37.6	51.9	47 1

Leaching Removes The Available Nitrogen.—The figures given in the above tables representing the percentage of loss of fertilizing constituents from the manure do not tell the whole story. The nitrogen in the portion removed by leaching is more valuable per pound than that which remains, because it is in a form more immediately available to the crop. This fact is strikingly shown in an experiment at the New Jersey Experiment Station in which two plots were treated

with quantities of fresh and leached manures which would give exactly the same amount of nitrogen The results, stated in percentage of gain over a plot receiving no manure, are given below.

PER CENT GAIN IN YIELD FROM MANURE

	Fresh Manure	*Leached Manure*
First year	52.7	41.5
Second year	180.4	96.8
Third year	117.5	89.6
Average	116.9	76.0

Open Yard Feeding a Wasteful Practice.—Upon a majority of the farms in America, perhaps, the cattle are fed during the winter in open lots, the manure not being hauled away until the following summer or fall, if indeed it is removed at all This method of feeding presents ideal conditions for **excessive losses** from leaching, and it is safe to say that more than half the fertilizing value of the manure is lost where this practice is pursued. In the corn belt of this country for instance, large numbers of cattle are fed during the winter, and it is not unusual to see a large feeding lot covered to a considerable depth with manure which is spread out and exposed to the weather in such a way that the maximum effects of leaching must take place There is no doubt that considered from the fertility point of view alone these farms would be better off if the corn were sold from the farm, and the stover all plowed under.

Losses Due to Fermentation.—There is another source of loss in stored manure that may be quite as

wasteful as leaching, *i, e.*, what is known as "hot fermentation." Manure is very easily decomposed, and there is no doubt that decomposition begins almost as soon as the excrement is voided by the animal. The first evidence of decomposition or fermentation is the odor of ammonia that is noticeable in the barn, especially in the morning, if the stable has been closed dur-

Open lot feeding as extensively practiced in the "corn belt." More than half the value of the manure is lost by this method of feeding

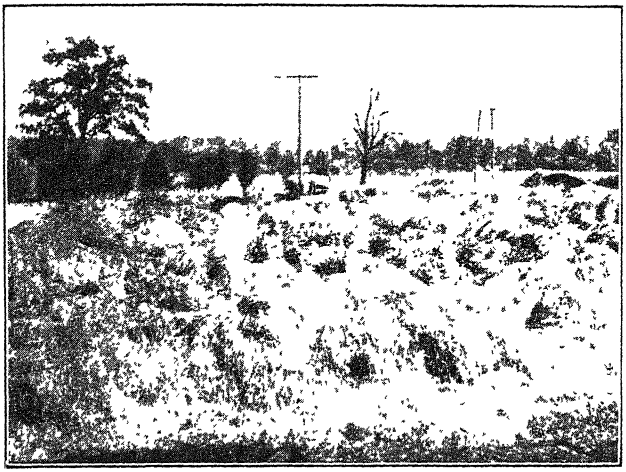
ing the night. This is due to rapid decomposition of urea, a nitrogeneous substance found in the urine. Ammonia contains nitrogen, and when its odor is perceptible it is a sign that nitrogen is being given off into the air, and that the manure, therefore, is undergoing a loss of this valuable constituent. The early decomposition of the urea will not be so likely to occur if plenty of absorbing material is used.

The fermentation of manure is due to different forms of bacteria. Some of these germs can exist only in the presence of oxygen, and are called "ærobic" bacteria, while others do not require free oxygen, and are designated as "anærobic" bacteria. The ærobic organisms are responsible for the hot fermentation which is the cause of great loss of value in manure. It is well known that if manure is thrown loosely into a heap, especially if it contains large quantities of horse or sheep excrement, it soon becomes very hot and dry and oftentimes white or "fire-fanged" as it is popularly termed. During this process large losses of nitrogen are occurring. Experiments conducted to show the loss due to fermentation alone indicate that from thirty to eighty per cent of the nitrogen is removed, but that the phosphoric acid and potash are not affected. In the case of the fire-fanged material in one experiment it was found that all of the nitrogen was lost. As the value of manure depends for the most part on the nitrogen content, it follows that more than half its worth may be lost by hot fermentation.

If the manure heap is so compact that the air cannot penetrate it the ærobic bacteria are unable to live, and hence hot fermentation is not possible. The presence of a large quantity of water also checks this kind of decomposition, and for that reason the excrement of cows and pigs is not so subject to hot fermentation as is that of horses and sheep. Where the manure is in a compact mass the fermentations that take place are due to the anærobic organisms. These bacteria cause decompositions in the manure which convert the insoluble plant food in the excrement into soluble forms,

but do so with little loss of the fertilizing constituents provided that the heap is protected from leaching rains.

Always Some Loss in Stored Manures.—Even under the best of conditions it is impossible entirely to eliminate losses in stored manure, although if properly preserved the loss may be limited to about ten per cent of the nitrogen, and none of the other two constituents This loss, however, is insignificant in comparison



Waste of manure in a market garden. The manure from the city stables was thrown into a loose pile and allowed to undergo hot fermentation and be leached by the rains. It should have been carefully piled and protected from the weather

with the losses which result from not saving the urine, from leaching due to rains, or from allowing the manure to undergo hot fermentations, all of which waste may be prevented to a great extent as will be explained in the next chapter.

CHAPTER XIV

PRESERVATION OF MANURE

Barn Floors Should be Perfectly Tight.—The great value of the manure produced on the farm, and the losses that may occur in it have been discussed at some length. The next point to be considered is the best method of caring for manure so as to prevent these losses as far as possible. Much that will be said under this heading has undoubtedly been already suggested to the reader by his perusal of the preceding pages, but the subject is of sufficient importance to justify devoting some space to it, even though repetition becomes necessary.

Attention has been called to the fact that over one-half of the value of the manure is in the liquid excrement, and it is desired to emphasize the statement, that the first consideration in caring for manure is to have that part of the barn floor upon which the excrement falls so tight that none of the liquid can drain away. The manure trough behind the cattle, especially, should be made absolutely tight by the use of pitch, cement or some other material that is impervious to water. In addition to this care should be used to supply litter in quantities large enough to absorb the urine so thoroughly that the manure may be removed without loss from dripping. If the farmer possesses a feed cutter he will be well repaid for cutting up all of the bedding materials. Straw cut in one inch lengths, for

instance, will absorb about three times as much urine as long straw. Cutting the bedding not only increases its absorptive power, but leaves the manure in a condition in which it is much more easily handled. Prominent stockmen have asserted that the greater ease with which manure containing short bedding can be removed, and spread, well repays the cost and trouble of cutting all the litter, to say nothing of the saving in bedding materials, and the latter is an important item on a farm that is stocked to its full capaciy.

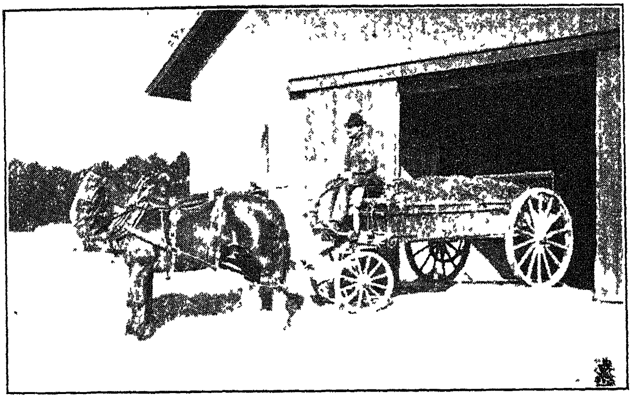
Preservatives May be Used in the Barn.—Most of the nitrogen present in the urine exists in the compound known as urea. This is very readily decomposed by bacteria and changed into a compound of ammonia and carbonic acid, and is known as "carbonate of ammonia." This substance is volatile, and is sometimes given off into the air in such quantities as to be readily detected by the nose (*i. e.*, by the odor or ammonia). This kind of decomposition takes place more readily in horse and sheep manures than in that from cattle or swine, as anyone can testify who has taken care of these animals when confined in closed barns No doubt the reader has gone into the horse barn on a winter morning when there was so much ammonia in the air that it "made the eyes water." When the odor of ammonia is perceptible it means that nitrogen is being given off from the manure, and the loss from this source may be an item of considerable importance. This loss may be prevented to some extent by the use of gypsum or land-plaster. The addition of this substance to a solution of carbonate of ammonia brings about a chemical change that converts

the ammonia into a compound that is not volatile, and hence does not pass off into the air, and at the same time the gypsum increases the value of the manure in other ways, as will be seen later. In using gypsum scatter it on the floor immediately after the barn is cleaned, and before the fresh bedding is spread. From one-half to one pound per animal each day is the amount most commonly used, although more will do no harm. It will probably pay better to apply all the land-plaster used on the farm with the manure than to sow it directly on the ground.

Kainite, muriate of potash and acid phosphate or super-phosphate are often recommended as preservatives for manure, and to prevent the loss of nitrogen. These substances are all said to be injurious to the hoofs of animals, and when used should be scattered on the floor and carefully covered with bedding. While many of the experiments seem to indicate that these materials (gypsum included) are efficient in preventing loss of nitrogen it must be admitted that there is great difference of opinion among authorities as to their merits as preservatives. Some experiments have indicated that nothing is so efficacious in preventing the loss of nitrogen from the manure as a liberal application of dry earth to the stable floor, especially if the soil used contains a large amount of humus. In some sections of the country it is considered good practice to collect and dry out muck soil for use in the stable in connection with the bedding. There is no doubt that this prevents the loss of ammonia, if properly used. Dry earth should not be used in too large quantities, however, for if sufficient is added to make the

manure very dry it will cause loss of nitrogen instead of preventing it.

Manure Should be Used When Fresh.—As has been said before, manure is never so valuable as when perfectly fresh; for it is impossible even under the best system of management to prevent entirely loss of its fertilizing ingredients. For this reason the plan of



The best method to prevent loss in manure is to haul it to the field as fast as it is made. This method should be practiced whenever the conditions are favorable

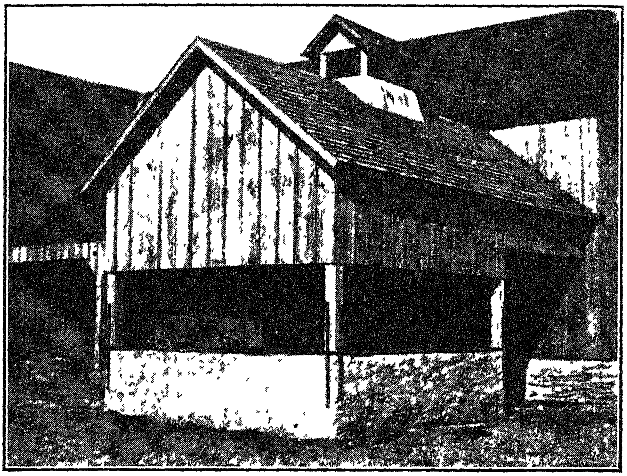
hauling the manure from the barn directly to the field is to be recommended whenever there is a field available and the weather is suitable. This method of handling the manure has many points that commend it to the American farmer. In the first place it is the most economical of time and labor, as the manure has to be handled but once, and, if the barns are conveniently constructed, can be removed to the field with little more labor than is required to place it in the heap if it is

stored. Where the manure is allowed to collect for long periods it becomes almost impossible to find the time and help necessary to haul it to the field, and the temptation to neglect it entirely is almost irresistible. Again, almost the total value of the manure is realized when it is removed directly to the field and spread over the surface of the ground. To be sure the rains falling on this manure will leach out the soluble portion, but now it will be carried into the soil where it is needed. The soluble constituents of the manure are "fixed" by the soil so that there is no danger of their being lost. If the manure is spread in a thin layer it will not heat, so there will be no loss from hot fermentation, and it has been demonstrated that where manure simply dries out when spread on the ground there is no loss of valuable constituents.

Stored Manure Should be Protected From the Weather.—It is not always possible to remove the manure to the field immediately, for there may be none ready to receive it or the weather may be such as to make it undesirable to haul over the ground. In that case it becomes necessary to store the manure for a time, and the question is how can this be done with the least loss, for it is impossible entirely to prevent loss in stored manures.

In the preceding chapter it was shown that the two sources of loss in fertilizing value in the manure after it is removed from the barn are leaching, due to rains, and hot fermentation. Obviously if the maximum value of the manure is to be retained these two injurious processes must be prevented. The effect of leaching rains may be overcome in two ways, by providing

water tight receptacles so that the liquid cannot run away, or by keeping the manure under cover so as to protect it from the rains. The first of these two methods is in general use in some sections of Europe Pits or cisterns of cement or other impervious material are built in which to store the manure and in some cases



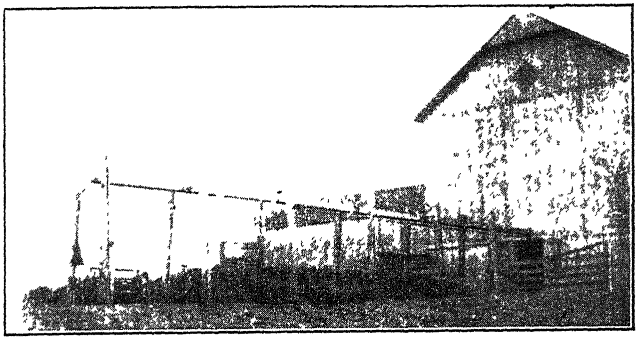
One solution of the manure problem. This shed is used to store manure only during the periods when it cannot be hauled to the field

a pump is provided so that the liquid may be pumped up, and allowed again to run over the solid portion to hasten and control its decay. While this process results in the production of manure of excellent quality it has little to recommend it to the American farmer, for it requires too much time and labor to prepare it, and it is not easily applied to the field. Protection of the manure from leaching rains by keeping it under

cover is more practical and should be in general use, for an inexpensive shed or lean-to is all that is needed. Where it is possible to provide the shed with a floor of some water tight material it is of course desirable to do so, as that prevents any danger of loss of liquid excrement that might not be properly absorbed by the bedding.

Hot Fermentation Must be Prevented.—The whole secret of preventing hot fermentation may be summed up in these few words, "Keep the manure heap compact and moist." It has been shown that the heating of manure is caused by a class of bacteria which require free oxygen for the performance of their functions. Unless these bacteria are provided with sufficient air it is impossible for them to live, and consequently hot fermentation cannot occur. In building the manure pile, therefore, great care should be taken to have the heap well compacted by tramping or other means. Each daily addition to the pile should be firmly packed into place, and the sides and top of the heap should be made smooth and firm in order to exclude as much air as possible. If the pile is made in this way the ærobic bacteria soon use all the air that is enclosed in it, and the manure never becomes very hot. The presence of an abundance of moisture tends to prevent hot fermentation due first to the cooling effect of the moisture itself, and to the fact that the moisture prevents the entrance of air. The manure heap should be carefully watched, and water added to it occasionally if it shows any tendency to become too dry. Keeping the pile compact and damp in this way will stop the injurious hot fermentation but does not

interfere with the decay due to anærobic bacteria. The latter is beneficial because it decomposes the organic matter of the manure in such a way that the plant food becomes more available and the manure is greatly improved in its mechanical condition. The first step in the preservation of manure should be the mixing of the different kinds produced on the farm, for in this way the rapid fermentation that would take place in the drier horse and sheep manure is checked by the



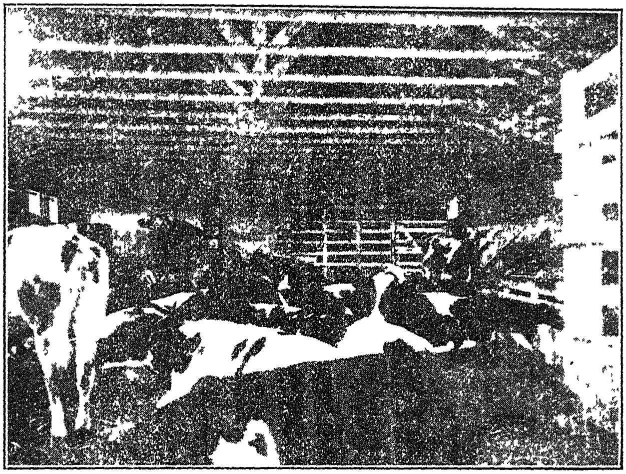
A convenient method for removing the manure from the barn, but some means should be provided to protect the manure from the weather until it can be hauled to the field.

more moist cow and pig excrement. When it is possible the manure should be turned occasionally for this causes it to decompose more readily and evenly. When necessary to store the manure for some time it is a good plan to cover the heap with an inch or two of earth. This prevents the escape of any ammonia that may be formed, as the earth has the power of fixing and retaining the ammonia.

Covered Barnyards Save Manure.—Roberts and other writers recommend the use of covered barnyards for the preservation of manure. These are simply sheds with good roofs with or without sides and large enough to allow the cattle some room in which to move about. The bottom is excavated a few inches, and made tight by puddling and pounding the clay, or by the use of cement. As the manure is removed from the barn it should be spread evenly on the floor of the covered yard. It will then be tramped into a compact mass by the moving about of the cattle and kept moist by the liquid excrement. The manure produced in this way is of excellent quality, can be easily handled when its removal is necessary and experiments indicate that the losses are reduced to a minimum. The advantages of such a covered yard as a place in which the animals will take mild exercise in severe weather will be apparent to most farmers.

A recent circular from the Illinois station presents the views of a number of practical dairymen who have been in the habit of allowing their cows the freedom of a covered barnyard, and using the stable only at milking time. The data collected seemed so favorable that the plan was put into operation at the station farm. Twenty-two cows were cared for in this way in a shed 30 by 68 feet, having mangers on each side and bull pens in two corners, and the results of this trial were considered most satisfactory. It is said that the cows keep cleaner than when stabled and that the milking barn is in a more sanitary condition, consequently, it is easier to produce clean milk. Labor is saved, as the shed can be bedded more easily and quickly than the

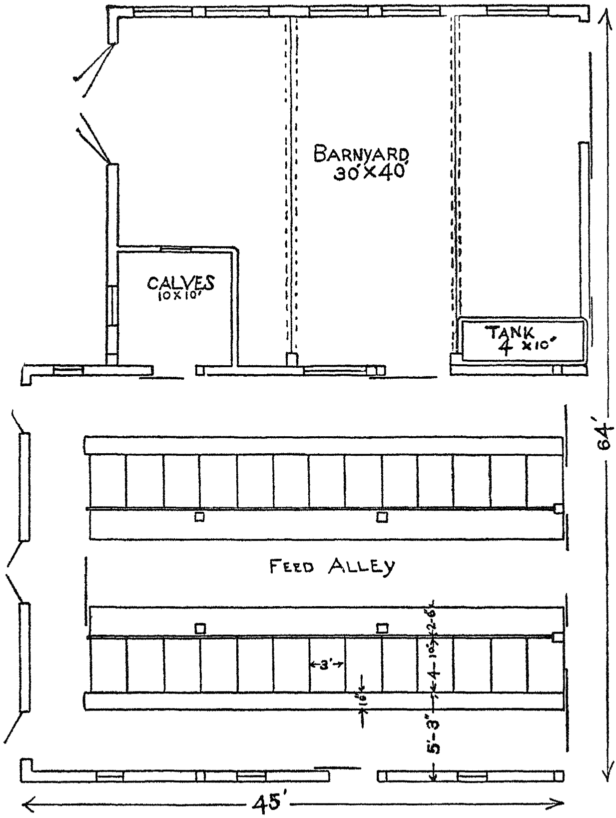
stalls; there is little stable cleaning to be done and the manure is hauled directly from the shed to the field when most convenient, and when there is least likelihood of damage to the ground by tramping. All the liquid excrement is absorbed, and if only sufficient bedding is used to keep the cows clean they tramp the



The covered barnyard is probably the very best means of preserving manure

manure so thoroughly that it does not heat enough to make the air impure

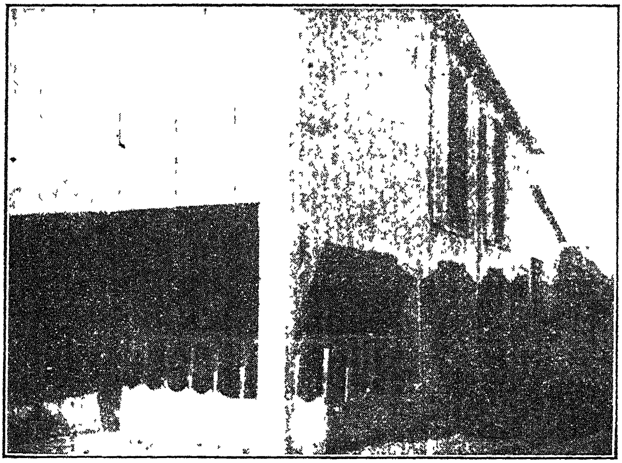
The plan followed by many farmers of throwing horse and cattle manure into a basement room, and allowing it to be worked over by the hogs is perhaps as good a method as could be devised when considered from the standpoint of the preservation of manure. The working over and tramping of the manure by the swine, accompanied by the addition of their own moist



The covered barnyard, as found on an Ohio dairy farm. When the new dairy barn (a section of which is shown in the lower part of the drawing) was built, the old barn was retained for use as a covered barnyard

excrement controls the fermentation so as to prevent undue heating, and very little fertilizing value is lost from manure produced in this way if the number of pigs is sufficient to work it over thoroughly.

Deep Stall Manure.—A method of preserving manure that is in use in some parts of Europe is what is known as the "deep stall method." The stalls in which



A little expenditure of time and money would convert this into a covered feeding place where the manure would be fully protected

the cattle stand are excavated for some depth below the general level of the barn floor, and every day the manure is spread evenly over the stall, and a liberal amount of bedding added. The mixture of excrement and bedding is firmly packed by the feet of the cattle and is not removed until the end of the winter, the surface of the manure by this time being above the level of the floor. The manure produced in this way is of

excellent quality and suffers very little loss in fertilizing value. This method will hardly commend itself to the farmers of this country for sanitary reasons, especially if they are engaged in dairy husbandry.

How to Care for Exposed Manure.—Occasionally it becomes absolutely necessary to store the manure when no cover of any kind is at hand In case it must be left in the open, the heap should be made so high that even the hardest rains will not soak entirely through it. The sides of the pile should be kept as nearly perpendicular as possible, and the top should dip slightly toward the center and great care be exercised to make the heap compact Complete saturation of the manure does no harm, but any water draining away from the heap is certain to carry with it large quantities of plant food

Composting Manures.—Any method of storing manure requires considerable labor, and for that reason is to be avoided in general farming whenever it is possible to use it in the fresh condition. In market gardening, on the other hand, such quantities of manure are used that it is necessary to have it thoroughly rotted before applying, as otherwise the crop would suffer from the heating effect that the large amount of raw manure would have on the soil. While the manure may be rotted by keeping it in a moist, compact heap as described in the previous section, it must be remembered that the manure commonly used by market gardeners is the horse manure from the city stables. This heats so rapidly that special care is necessary to prevent hot fermentation, and the pile must be frequently moistened. Many market gardeners prefer to compost the

manure with earth, peat or muck. This is done by making a foundation of about six inches of dirt, and on top of this placing alternate layers of manure and soil, moistening the mass as the heap grows. The sides and top should be nicely smoothed off and the mass covered with a thin layer of earth to prevent loss of nitrogen. After about two months the pile should be turned over, the materials thoroughly mixed and more water added if necessary to keep the compost moist.

A compost in great favor with greenhouse men is one made of manure and sod, these materials being piled in alternate layers as described above. This gives the fibrous compost so desirable for bench and pot work. Any of the refuse organic materials of the farm or garden may be used in composts. Weeds, refuse parts of plants, dead animals, kitchen wastes, etc., may be added to the manure-earth mixture, or composted separately, for handled in this way they decompose rapidly and without offensive odors. The presence of the earth decreases the loss of ammonia where highly nitrogeneous materials are used.

Some market gardeners throw the horse manure as it comes from the city stables into the pig pens to be first worked over by the pigs, and then composted with the earth, and this plan is no doubt a wise one.

In using composts a good practice is to add bone meal, and one of the potash salts to the heap. In this way the plant food in the bone meal is made available to the plants, and the compost is made more valuable.

It occasionally happens that one wishes to produce a stock of well rotted manure in a very short time.

This can be done by mixing the fresh manure with a small quantity of freshly slaked lime. In this way the manure is made to decay very rapidly, but as the decomposition is probably attended by more loss of nitrogen than usually occurs in composts it is not to be recommended for general use.

CHAPTER XV

APPLYING MANURE

Best Used as a Top Dressing.—Nature applies all her fertilizers to the surface of the ground. Many farmers have come to the conclusion that Nature's method is the best, and whenever possible are using manure as a top dressing. The tendency is for the elements of fertility to pass gradually down into the soil, especially the compounds containing nitrogen For this reason it is best to apply the fertilizer to the surface so that as the soluble food descends it comes into contact with plant roots, and is not carried to such a depth as to be beyond their reach. Manure to be used in this way must be so fine as not to interfere seriously with subsequent tillage of the ground. This condition of fineness generally exists if the manure is well rotted but even fresh manure may be utilized as a top dressing if cut straw or other fine material has been used for bedding. It is well to apply the manure directly after plowing and to incorporate it thoroughly with the soil by use of the harrow or cultivator preparatory to planting the field. Another reason in favor of top dressing over other methods of applying manure is that the organic matter added to the surface soil in this way acts as a mulch, and tends to prevent the evaporation of water from the soil.

Should be Spread Immediately.—Two general methods for the application of manure are in common

use, one is to throw it into heaps where it is allowed to remain some time before being spread, the other to broadcast it directly from the wagon. The first method is objectionable for several reasons. In the first place it increases the work necessary to spread the manure as it must be handled twice, and it takes no more labor to spread it from the wagon than from the heap on the ground. When piled in this way it is very often allowed to stand for some days at great risk of injurious fermentations, such as have been described. The leachings from these heaps make the spots directly beneath more fertile than the rest of the field, and hence produce a rank growth at those places. No doubt the reader has often seen a field where he could detect every spot upon which the manure heap had been placed by the brighter green color and more luxuriant growth of the crop This uneven growth is undesirable because in the case of grains it increases the danger of lodging in the more fertile spots, and in any case it results in unevenness in the maturity of the crop. A crop that has a large supply of plant food, for instance, has a longer period of growth than one with a meager supply, and consequently is later in maturing. If, therefore, the field is very uneven in fertility a part of the crop will be ready to harvest some time before the rest has matured. If the manure is spread directly from the wagon not only is the labor lessened but the danger of unevenness in growth is to some extent avoided. There is no likelihood of loss in the value of the manure when it is spread in a thin layer on the ground, as has already been stated.

Manure spreaders are now being offered for sale of

such efficiency that they are likely to come into general use. Some recent experiments seem to indicate that manure gives better returns when spread by the machine than it does when applied by hand. Whatever method is used to spread the manure it will readily be seen that the finer the material the easier it will

Placing the manure in piles in the field is an objectionable practice. The manure should be broadcasted as soon as it is hauled to the field

be to distribute it evenly. Where very coarse manure is used it is sometimes advantageous to supplement the spreading from the wagon by the use of a drag that will break up the larger lumps, and thus scatter it more uniformly.

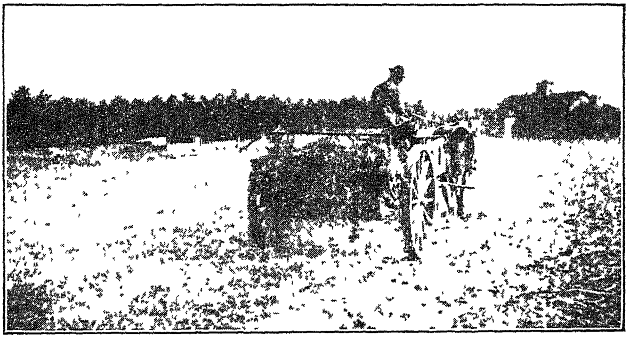
Depth to Cover Manure.—Where the manure is so coarse as to interfere with tillage it becomes necessary to plow it under, and in this case good judgment is necessary to prevent its being covered to too great a depth. Especially in clay soils, where the air does not readily enter, it is possible to bury the manure so

deeply as to prevent decay. In the case of porous soils on the other hand this danger is not so great. In compact soils the manure should probably never be covered to a greater depth than four inches while in sandy soils the depth might be much greater. In general it may be said that the coarser the manure the greater the depth to which it may be buried, while fine and well decayed manure on the contrary should remain near the surface. In very dry seasons much harm may be done to the soil by plowing under large quantities of coarse manure as there may not be sufficient moisture in the soil to bring about the decomposition of the organic matter. The undecayed material may cause serious injury to the physical condition of the soil as was noted in the discussion of green manure, and the suggestion regarding the use of the roller holds good in this case.

Applying to Grass Land.—A practice that is highly recommended is to apply the manure, especially that of the summer and early fall, to meadow or sod land that is to be plowed and planted the following spring. In this way of utilizing manure the soluble part as it is washed out by the rains is used by the growing crop, and thus the losses due to leaching are avoided, and as the stubble or sod is turned under the entire amount of plant food is in position to be made use of by the succeeding crop. The permanent pastures should not be neglected in manuring and will well repay liberal applications. It is well to use the drag mentioned above on the pastures so as to spread the droppings of the cattle in a uniform manner over the surface. When manure is properly applied to pastures

or meadows it is beneficial in conserving the moisture as well as in supplying plant food, and in inducing a longer season of growth.

Fresh and Rotted Manures Compared.—Few questions have been more discussed by the agricultural press than the relative merits of fresh and rotted manures, and the apparently inconsistent results reported by different farmers are probably due more to the var-



Manure spreader in action The spreader distributes the manure more evenly than can be done by hand, and some experiments indicate that a larger yield is obtained from a ton of manure when applied with the machine

ious kinds of soil on which the manures were used than to any difference in the values of the manures themselves. Considered from the standpoint of the soil alone, it will be found that on heavy soils containing large amounts of clay more benefit will be derived from raw manures than from those that are well rotted. The fresh manure warms these naturally cold soils, makes them more porous, and the fermentations that take place during its decay tend to make the soil more

mellow and to set free the "locked up" plant food Rotted manure has the same effect as that which is fresh but in a less marked degree. On light or sandy soils, on the other hand, those manures that are well decomposed will be found more beneficial. Such soils are likely to suffer from the heating and drying effect of raw manure, and to have their porosity increase to an undesirable extent. The manure used on these soils if applied in large quantities, should be completely decayed, and then it will improve the mechanical condition of the soil, and materially increase its moisture retaining power.

Raw manure induces rank growth, and for that reason is objectionable for use on the small grains where the product desired is the grain and not the yield of leaf and stem. If manure is used directly on these crops it should be thoroughly decomposed. Corn, millet and hay crops, on the contrary, are usually benefited by liberal applications of fresh manure Corn especially is a gross feeder and apparently is not injured by raw manure even when used in excessive quantities. In fact it may be said that when the farmer is in doubt as to where to apply the manure he should use it on the corn. Manures that are at all fresh are injurious to sugar beets and tobacco, in the former case producing a large beet that is low in sugar content and in the latter a coarse and undesirable leaf. It is also a well known fact that raw manure is likely to cause wheat to lodge.

Instead of using manure directly on the grain, beets or tobacco it is customary in some parts of the country to apply it liberally to corn, and plant the field to the

above mentioned crops the following year. If it is used in this way, there is no danger of inducing rank growth.

Amount to Apply.—In a few instances manures are wasted by too liberal use. For ordinary farm crops it is not customary to use more than eight to ten tons

Manure spread on the snow. There is no objection to this method of handling manure if the ground is fairly level and the snow not too deep. It is certainly better than to allow the manure to remain exposed in the barnyard

per acre, and on general principles it may be stated that somewhat frequent light dressings pay better than very large ones given at long intervals. On the other hand, the amount of manure produced on the average farm is so small when compared with the land to be fertilized that it would be utterly impossible to spread it over all the farm yearly. For this reason it is a good plan to apply the manure to one crop in a rotation, thus covering only a fraction of the farm each

year. The following rotation which is used by a well known dairyman is an example that will explain the last statement: Corn one year, grain one year, clover and timothy two or three years. The manure is applied the last year the field is in sod. A second rotation in common use is as follows: Corn (manured) grain, grain, clover. Chemical fertilizers are ofter used on one or both grain crops as well.

CHAPTER XVI

BARNYARD MANURE AND THE MAINTENANCE OF FERTILITY

Manure as a Crop Producer.—Some difference of opinion exists among farmers as to the relative value of barnyard manure and commercial fertilizers for crop production, but it is worthy of note that those who are most diligent in caring for the manure have most faith in its worth as a fertilizer The fact that barnyard manure has been used so universally by agriculturalists for so many centuries is one of the strongest arguments in its favor. That the popular estimate of its value is established by scientific experiment is well shown by investigations carried on at Rothamsted. On certain plots, as has been mentioned, crops have been grown continuously with no fertilizer of any kind added, on other plots barnyard manure at the rate of 14 tons to the acre has been used every year, and on still others various combinations of commercial fertilizers have been tested. The following table gives the yields of barley and wheat from the unmanured plots, the plots dressed with barnyard manure, and the highest results obtained from the use of any combination of fertilizing materials. The tests extend over 40 years, but to shorten the table the results are given here in averages for five eight-year periods. (Fractions have been omitted.)

	BARLEY *Bushels per Acre*			*WHEAT* *Bushels per Acre*		
	No Manure	*Barnyard Manure*	*Commercial Fertilizers*	*No Manure*	*Barnyard Manure*	*Commercial Fertilizers*
1st 8 years	24	44	48	16	34	36
2nd 8 years	18	52	51	13	35	39
3rd 8 years	14	49	45	12	35	36
4th 8 years	14	52	42	10	28	32
5th 8 years	11	44	41	12	39	38
Average (40 years)	16	48	45	13	34	36

It will be seen that while both the fertilized plots gave much larger yields than the one receiving no addition of plant food, there is practically no difference between the plots dressed with barnyard manure and the best commercial fertilizers. This test is hardly fair to the barnyard manure as the quantities of commercial fertilizers applied were far in excess of anything used in general practice; the amount of nitrogen added to the wheat, for instance, being equivalent to that contained in 800 pounds of nitrate of soda, which would cost practically as much as the wheat would bring on the market. In all probability, if these experiments had been conducted in this country the showing would have been more favorable to barnyard manure. It has been explained that the materials in the manure must undergo nitrification before the nitrogen

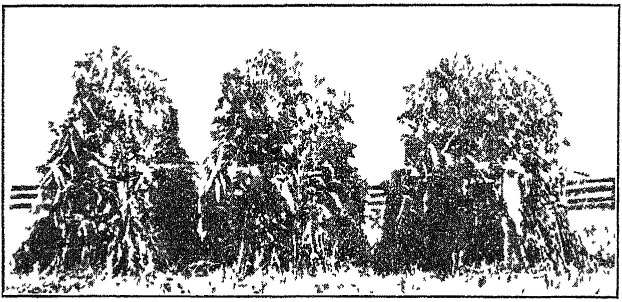
becomes available to the plants and this process takes place so much more rapidly in this country than in England that it is easy to believe better returns might be obtained from barnyard manure under American conditions.

Lasting Effect of Manure.—Barnyard manure differs from other fertilizers in its lasting effect when applied to the soil. At Rothamsted, in connection with the above experiment, one plot was manured annually for 20 years and then received no manure for the next 20 years. In the accompanying table are given the yields of barley in averages for five year periods on the plot which was never manured, and the plot that had been manured the previous 20 years. The figures given for the second plot represent the effect of the residual manure, as no fertilizer was added during the period covered by the table.

	Unmanured Every year	*Effect of Residual Manure*
First 5 years	13	39
Second 5 years	14	29
Third 5 years	14	30
Fourth 5 years	12	23
Average (20 yrs)	13.25	30

The table shows that the effect of the manure was perceptible in yield for at least 20 years after the last application. It is more than likely that the more rapid rate of nitrification in this country might materially shorten the period in which the lasting effect of the manure would be observable, and perhaps the influence of the residual manure would have disappeared in a shorter time than twenty years.

Barnyard Manure the Best Fertilizer.—When everything is taken into consideration barnyard manure, which has been properly cared for, is undoubtedly the best substance that the farmer can use as a fertilizer. It supplies all the elements of plant food, and while these are not all in forms immediately available to the plant, a comparison of manure and commercial fertilizers during a period of several years is practically



Corn fertilized with stable manure. This plot gave a yield of 34,800 pounds of ensilage per acre. Compare with illustration on opposite page

always favorable to the former. The value of barnyard manure cannot be estimated from the content of nitrogen, phosphoric acid and potash alone, for it is probably as valuable on account of its effect on the physical condition of the soil as for the plant food which it contains. It has no equal among fertilizers as a humus former, and the usefulness of humus in improving the tilth of the soil and increasing its power to hold water was explained in an earlier chapter.

The use of the animal excrements is also beneficial because it increases the desirable fermentations, or

bacterial action, in the soil. In fact it seems certain that the farmer would be well repaid for applying the manure for its indirect effect in improving the condition of the soil, even though it contained none of the elements of plant food.

Barnyard manure is also the safest fertilizer to use especially by the inexperienced farmer or the one who is careless in his methods There is little danger of

Corn fertilized with a good complete fertilizer. This plot gave a yield of 29,000 pounds of ensilage per acre. Compare with illustration on opposite page

lasting injury to the soil from the use of manure, while it is possible to use commercial fertilizers in such a way as to make the soil poorer after their use than it was before.

Relation of Manure to Maintenance of Fertility.—The discovery of the fact that fully 80 per cent. of the fertilizing constituents of the crop can be recovered in the manure has thrown a new light on the subject of the maintenance of fertility. A number of the most prominent authorities on agriculture believe (and the belief seems perfectly plausible in view of the facts

already discussed) that in a system of strictly animal husbandry, where nothing is sold from the farm except animals or animal products, the fertility of the land may be maintained indefinitely without the purchase of fertilizers, provided the manure is properly utilized. This assumes, of course, that as nearly as possible the full value of the fresh manure is realized and that the losses, which have been discussed, are avoided. Not only may the fertility be maintained in this way but it may actually be increased, as has been demonstrated by a number of farmers.

It has been shown that where the crop is allowed to remain on the ground to decay, and become a part of the soil, the fertility of the land increases from year to year. The fact was also brought out that the soil contains large quantities of potential plant food, especially of the mineral elements and that each year a certain portion of this potential food is becoming available. The question that suggests itself is whether the food rendered available each year is sufficient to make up for the 20 per cent lost in feeding the crops to animals. There seems to be no reason to doubt that this is so in case of the mineral elements even if not true of nitrogen. The 20 per cent loss in feeding falls nearly altogether on the nitrogen while very little of the phosphoric acid and potash are lost; so that it is easy to realize that the supply of these two elements can be maintained by the use of the manure and a good system of tillage. The experiments at Rothamsted indicate that the growth of a crop of clover adds 75 pounds or more of nitrogen per acre to the soil, and consequently this suggests a method of replacing the nitro-

gen lost through feeding. Taking all things into consideration, it is evident that under the conditions mentioned above it is possible to keep a farm fertile indefinitely through the use of the barnyard manure produced upon it, supplemented by good tillage and the growth of leguminous crops. This statement holds true only where no crop is sold. In case the crop is sold the entire amount of fertilizing ingredients that it contains is removed from the farm. Where the farmer depends for his profit on the sale of animals and animal products, however, there is no doubt that the fertility can be maintained in the manner described, assuming that the farm was in a fair state of fertility at the start. Where large amounts of concentrates are used, as is often the case in dairy farming, there should be an increase in the fertility of the farm if the manure is properly handled.

Effect of Style of Farming on Fertility.—The facts brought out by this discussion of the subject of barnyard manure must have made it apparent that the losses in fertility are much greater in any system of farming where the crops are sold from the farm than where some form of animal husbandry is followed, especially if no commercial fertilizers are used. To bring this point more concretely before the reader the following diagram adapted from a Minnesota bulletin is given here.

To obtain the data upon which this diagram is based, four farms were assumed each containing 160 acres. On the first farm nothing but grain was raised, and all sold from the farm. The second was about equally divided between grain and stock farming, and the third

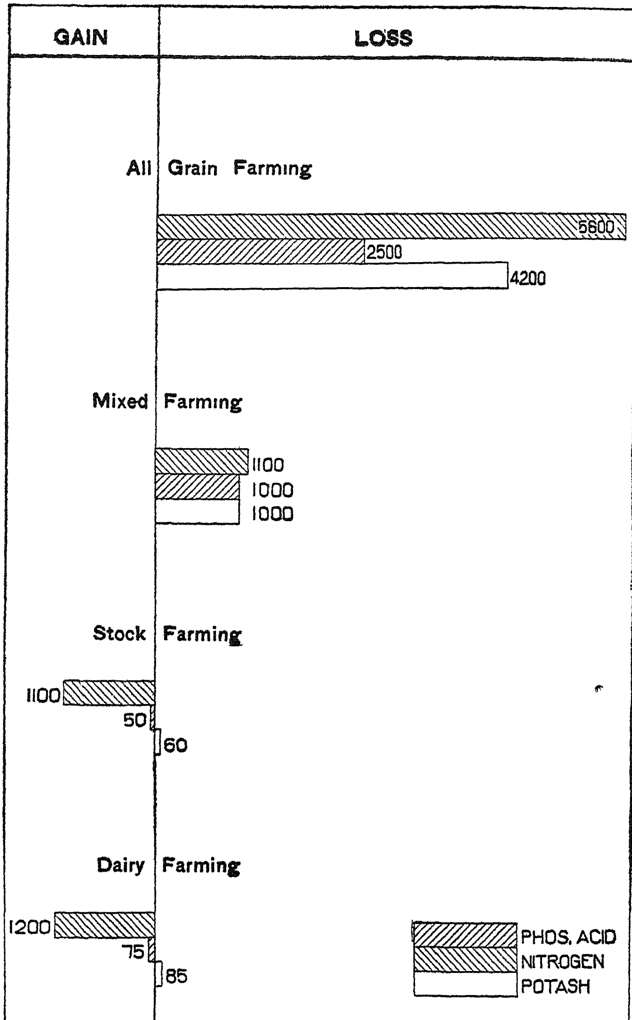
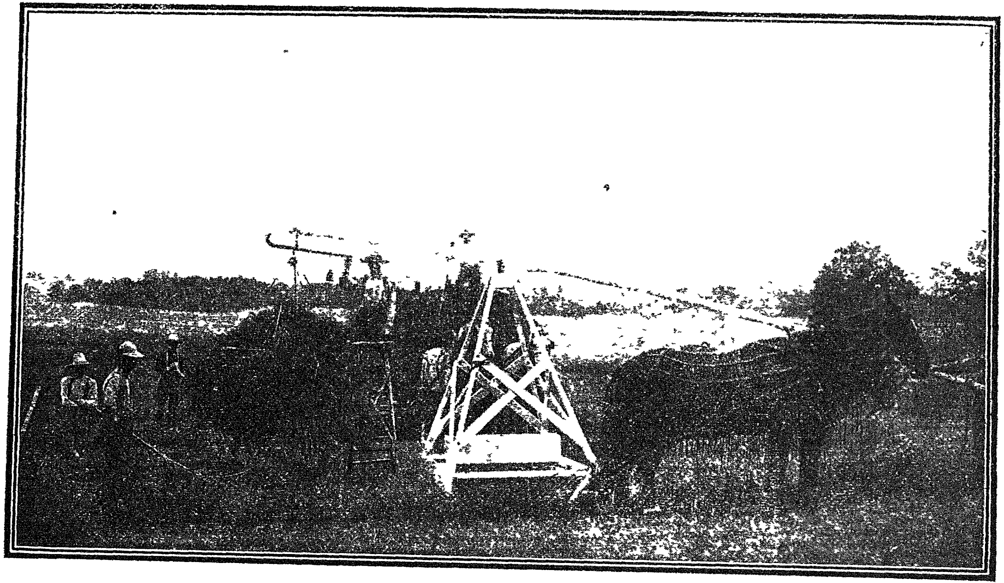


Diagram showing effect of style of farming on fertility

and fourth farms were devoted exclusively to stock raising and dairying respectively. In the last two cases a small amount of the farm produce was exchanged for mill products, which accounts for the slight gain in phosphoric acid, but it was assumed that no other concentrates or fertilizers were used. The decidedly smaller loss of nitrogen on the second farm, and the actual increase of nitrogen on the stock and dairy farms are due to the fixation of nitrogen from the growth of clover The figures represent the number of pounds of the fertilizing materials lost or gained on the farm in one year. No more striking illustration of the effect of the system of farming on the fertility of the land could be desired.

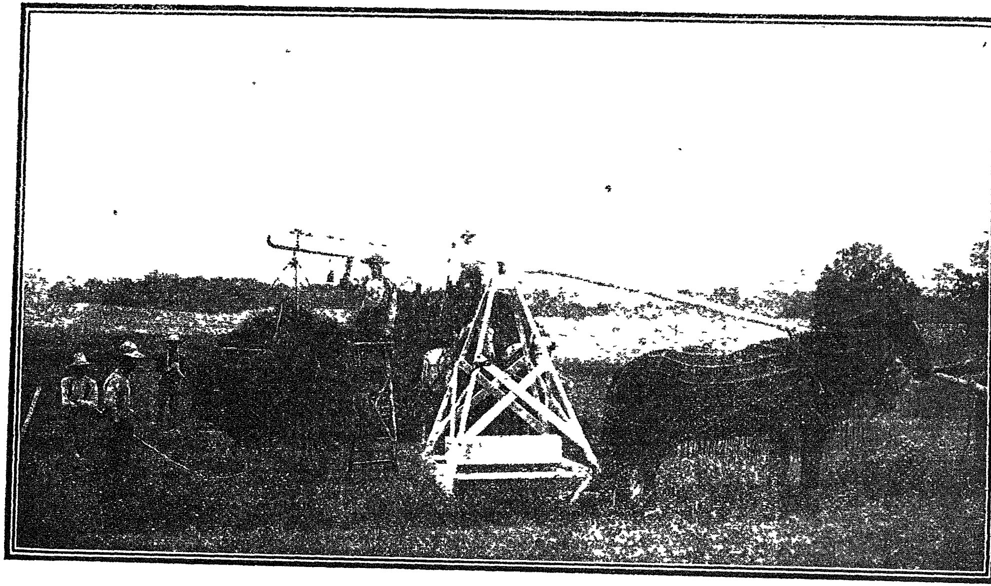


Weighing the crop on the fertilizer test plots. The yield must be carefully measured if accurate information regarding the relative value of the fertilizers is desired

CHAPTER XVII

GENERAL CONSIDERATIONS

Nitrogenous Materials.—It was shown in Part III that under a system of animal husbandry it is possible to maintain the fertility of the soil by means of the barnyard manure used in connection with leguminous crops, provided the best methods of tillage, etc., are used and all the materials raised are fed on the farm. Where a part or all of the crops produced are sold from the farm it sooner or later becomes necessary to supply plant food derived from outside sources. This is especially true in truck farming, where the crops raised are such as remove large quantities of plant food. The needed fertility is supplied to some extent by the manure produced in the city stables, and is best so supplied when possible, but this source of fertilizing material is obviously inadequate to furnish the required amount of plant food. The constantly growing demand for something that will increase the crop production has given rise to the fertilizer industry which is rapidly assuming gigantic proportions. At the present time over $50,000,000 are spent annually in the purchase of fertilizers in the United States, and it is probably no exaggeration to say that fully half of this is money thrown away. This is no argument against the use of commercial fertilizers but simply means that they should be used with judgment, and not used at



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all until actual investigation has shown them to be necessary.

Lack of Plant Food Not Sole Cause of Crop Failure.—"One must distinguish between lack of plant food in the soil and other conditions which prevent good crops, for lack of food is not the only cause that makes crops suffer. In some soils there is insufficient porosity, which causes the development of the roots to be checked. Lack of moisture, caking of soil, retention of stagnant water, deficiency of humus, lime, etc., unfavorable weather and other conditions may interfere with the healthy growth of plants and thus cause diminished crops, even when the plant has within reach all the food it needs. Under such circumstances the unfavorable conditions must be removed to secure good crops, which, according to the demands of special cases may be done by irrigating, draining, harrowing, hoeing, marling, mucking, etc. It may often happen that the soil contains an abundance of plant food, most of which is still unavailable. Under such circumstances an effort should be made to bring this food into an available condition as rapidly as the plants can use it, and this may be done by an improved system of tillage, together with the application of such indirect fertilizers as have the power to make insoluble plant food available."—Van Slyke.

Fertilizers Should Not Take Place of Tillage.—Too frequently fertilizers are made to take the place of tillage when they should be used to supplement it. That is, fertilizers are most likely to produce profitable results when conjoined with superior physical conditions of the soil, and in general terms it may be said

that the man who would obtain the best yield without fertilizers of any kind is the one most likely to realize a profit from their use.

"The fact that fertilizers may now be easily secured,

Thorough preparation of the soil is of prime importance in the growth of crops. The upper picture shows buckwheat grown on a soil which was carefully prepared. The lower cut shows a part of the same field which was hastily and poorly prepared, no fertilizer being used in either case. Commercial fertilizers should not be expected to take the place of good tillage and cultivation of the soil

and the ease of application, have encouraged a careless use, rather than a thoughtful expenditure of an equivalent amount of money or energy in the proper prepara-

tion of the soil. Of course it does not follow that no returns are secured from plant food applied under unfavorable conditions, though full returns cannot be secured under such circumstances. Good plant food is wasted, and the profit possible to be derived is largely reduced."—Voorhees.

What Are Commercial Fertilizers?—When it was first discovered that certain of the elements found in the soil are necessary to plant growth it naturally occurred to the agricultural investigators that it might be possible to renew the fertility of worn out soils by supplying these elements artificially. In the first experiments conducted along this line all the elements which the plant derives from the soil were supplied. As the investigations progressed it was discovered that increased production resulted in most instances from the addition of only three of these substances—*i. e.*, nitrogen, phosphoric acid and potash. In other words, it was determined that except in rare cases all the other elements exist in the soil in quantities sufficient to supply the needs of the plant, even when the available nitrogen, phosphoric acid and potash are practically exhausted. For this reason it is generally considered unnecessary to supply any of the elements of plant food except the three named above, and these substances have come to be known as the "essential ingredients of a fertilizer," and the only ones that give the fertilizer a commercial value.

All Fertilizers Made From a Few Basic Materials.—From what has been said it will be seen that any material that supplies one or more of these "essential ingredients" may be used as a commercial fertilizer,

provided it could be purchased at a price that would make its use profitable. As a matter of fact, the number of substances that are available for this purpose is somewhat limited, owing to the prohibitive prices which the others bring on the market. Many persons seem to think that there is something mysterious about the manufacture of fertilizers and some of the makers encourage this belief by pretending that they have some secret process of manufacture that enables them to produce a better product than their competitors, and far better than the farmer can mix himself.

The truth is that there are a limited number of basic materials from which all the different brands of fertilizers are made, and these basic substances are articles of commerce and can be purchased by anyone. The so-called "complete fertilizers" consist of two or more of these substances mixed together in the proportion to give the required per cent of nitrogen, phosphoric acid, and potash in the finished product. Some of these materials are commonly purchased unmixed, while others are rarely seen by the farmer except as one of the ingredients of a complete fertilizer. Some of these basic materials contain only one of the essential ingredients of a fertilizer, while others contain two, but usually one is in such excess that the substance is used chiefly to furnish that one element. It is possible, therefore, to separate the basic fertilizers into three classes, viz.,

1. Materials used chiefly as sources of nitrogen.
2. Materials used chiefly as sources of phosphoric acid.
3. Materials used chiefly as sources of potash.

In order to discuss intelligently the subject of commercial fertilizers it will be necessary to consider briefly the substances included in these different classes.

NITROGENOUS FERTILIZERS

The larger number of the materials of this class are composed of various kinds of refuse animal matter from the packing houses, soap and glue factories, etc. Only those in common use will be discussed here.

Dried Blood.—As its name signifies, this is the blood from the slaughter house rapidly dried by artificial heat and when ready for sale is in the form of a powder. Two grades of dried blood are found on the market known as the red and the black blood. The red blood is more carefully dried, and is not charred as is likely to be the case with the black blood, which is more rapidly dried. The red blood contains from 13 to 14 per cent of nitrogen, while the black is much less constant in composition and contains from 6 to 12 per cent.

Meat Meal, Azotin, Ammonite.—These are synonymous terms used to designate a meat product derived principally from the rendering establishments where the different portions of dead animals are utilized. When relatively pure it contains from 13 to 14 per cent of nitrogen.

Hoof Meal.—The principal source of this product is the glue factory, and it consists of the dried hoof or portions thereof ground to a fine powder. It is fairly uniform in composition and contains about 12 per cent of nitrogen.

Horn Meal is produced at the packing houses and in the factories where combs, buttons, etc., are manufactured. The chips and shavings are ground to a fine meal and sold as a fertilizer. It is quite uniform in composition, containing from 10 to 12 per cent of nitrogen, though in a very unavailable form.

Tankage consists of the dried animal wastes from the large slaughtering and rendering establishments. It is variable in composition owing to the fact that the proportions of the different ingredients of which it is composed may vary widely in different samples. As commonly made it may include offal, small bones, tendons, waste flesh, hair, etc. These materials are rendered for the extraction of the fat, and the residue is dried and ground to a meal of more or less fineness. Tankage contains phosphoric acid as well as nitrogen and the percentage of the two vary. As the nitrogen decreases the phosphoric acid increases, and *vice versa*. The variation of these two ingredients is so great that in trade tankage is always sold on the basis of its composition. Because it contains very considerable amounts of phosphoric acid its commercial value is not based wholly on its nitrogen content as is the case with dried blood and dried meat. Tankage contains from 4 to 9 per cent of nitrogen and from 3 to 12 per cent of phosphoric acid

Dried Fish or Fish Guano.—Most of the fish fertilizers are made from menhaden, a fish that is caught in large numbers along the Atlantic Coast. The fish are steamed and pressed to extract the oil and the remaining "pomace" is dried and ground. This material contains from 8 to 11 per cent of nitrogen and 3

to 5 per cent of phosphoric acid. Some of the fish fertilizers consist of the residue of the canning factories, but these are not so valuable as those derived from the menhaden

Leather Meal consists of the smaller scraps and chips from the leather industry ground into a meal which is sometimes used in the manufacture of fertilizers. Leather is fairly rich in nitrogen, but when one takes into consideration the fact that the one object in making leather is to render it resistant to decay, it will be evident that it is not a desirable substance to use as a fertilizer.

Cottonseed Meal and Linseed Meal were formerly used as nitrogenous manures, but their value as feeds is now so well recognized that they are no longer available as fertilizers.

Peruvian and Other Guanos are composed of the accumulated droppings of fish-eating birds, more or less mixed with the dead bodies of these birds. The most important source of this material was a group of islands lying off the coast of Peru, and its high value was due to its being produced in a rainless region Guano was formerly abundant, and was so much appreciated as a fertilizer that many substances in no way resembling the true guanos were called by that name. At the present time practically no guano of good quality is imported, and any product bearing that name should be looked upon with suspicion and purchased only upon analysis.

Sulphate of Ammonia is a by-product in the manufacture of coal gas, animal charcoal and coke. It resembles common salt somewhat in appearance, and is

the richest in nitrogen of all fertilizing materials, containing from 20 to 23 per cent. At the present time the high price of sulphate interferes with its extensive use as a fertilizer, although it gives excellent results on soils that contain plenty of lime. It should never be used on soils deficient in lime nor in connection with the ordinary potash fertilizers which contain chlorine.

Nitrate of Soda or Chili Saltpeter is a crystalline substance somewhat resembling coarse salt in appearance and is entirely soluble in water. It all comes from large deposits in Chili which supply over one million tons of nitrate a year to be used as a fertilizer. Chili saltpeter contains from 15 to 16 per cent of nitrogen in a form that is immediately available to the plant, and for this reason it is the most desirable nitrogenous fertilizer to use where immediate results are desired. It is not fixed by the soil and consequently should be supplied only as the crop can use it, and never applied to the ground when it is bare. As it is so easily washed from the soil it is considered best to use it in two or three applications instead of applying all at one time.

Relative Availability of Nitrogenous Fertilizers.—The percentage of nitrogen present in the different fertilizing materials as given in the previous section does not properly indicate their relative fertilizing value. Mention has repeatedly been made of the fact that the plant can make use of the nitrogen only when it is present in the soil in the form of nitrates. Nitrate of soda is the only fertilizer on the list that contains nitrogen in the nitrate condition, and consequently is the only one that adds nitrogen to the soil in a form that is

available to the plant without further change. All the other materials must undergo the process of nitrification, and have their nitrogen converted into nitrates before they can be used by the crop. It must be apparent, then, that the value of a nitrogenous fertilizer depends both upon its content of nitrogen, and the ease with which it is nitrified.

Of the list given above, sulphate of ammonia is the most easily converted into nitrates provided the soil is abundantly supplied with lime. Next in order comes dried blood. So many other uses are being discovered for dried blood, however, that the time is probably not far distant when it can no longer be used as a fertilizer.

The nitrogen in dried fish, tankage, hoof meal and bone meal are readily changed by nitrification and rank next to blood meal. Horn meal, on the other hand, decomposes very slowly, and the nitrification of leather is so slow as to make it practically worthless as a fertilizer.

Experiments up to date indicate that if nitrate of soda is rated at 100 per cent, the availibility of the other materials would be as follows:

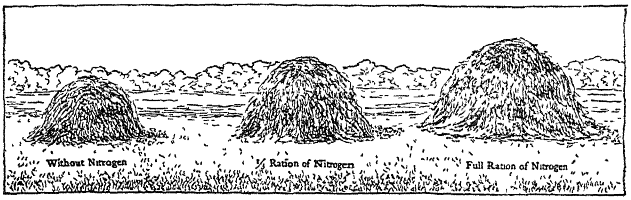
	Per cent.
Nitrate of soda	100
Blood and cottonseed meal	70
Fish, hoof meal	65
Bone and tankage	60
Leather and wool waste	2 to 30

"If for example the increased yield of oats due to the application of nitrate of soda is 1,000 pounds, the

yield from blood would be 700 pounds, from hoof meal 650 pounds and from leather 20 to 300 pounds."

These statements indicate how little an analysis of a fertilizer which gives only the per cent of nitrogen or ammonia tells of the real value as a supplier of nitrogen, and show very clearly that to arrive at any conclusion regarding the value of a nitrogenous fertilizer one should know the source or condition of the nitrogen as well as the per cent.

Two or three suggestions for the selection of nitro-



Effect of top dressing grass land with nitrate of soda. The plot on the left received no nitrate, the center one half ration, and the one on the right a full ration of nitrate

gen fertilizers may be deduced from this discussion. For those crops which begin their growth early in the spring the best results will follow the use of Chili saltpeter, as the soil is likely to be poor in nitrates and the process of nitrification slow at that time. Such crops as have very short periods of growth will respond best to nitrogen in nitrates. Corn, on the other hand, and the other crops which make their growth after the season is well advanced can use the slower acting fertilizers, as can also those crops which occupy the ground permanently. Some agriculturalists prefer to use a fertilizer containing nitrogen in three forms

for the crops that grow during the greater part of the season, a little nitrate of soda for immediate use, sulphate of ammonia to supply nitrogen a little later and tankage to carry the plant to maturity, all these materials being mixed and applied at one time.

Nitrogen is Expensive.—Nitrogen is the most expensive element to supply in commercial fertilizers, costing as it does at least three times as much a pound as either phosphoric acid or potash. In ordinary or "extensive" farming it is seldom profitable to use nitrogenous fertilizers for the nitrogen of the soil can be readily maintained by means of the farm manure, and a proper use of leguminous crops in the rotation. Market gardening and other forms of intensive farming call for a liberal use of fertilizers containing nitrogen. A careful study of the materials used to supply nitrogen should be made by those engaged in this style of farming for as Wagner says, "The art of manuring is dependent upon a rational application of nitrogen."

CHAPTER XVIII

POTASH AND PHOSPHATE FERTILIZERS

Potash Sometimes Necessary in a Fertilizer.—It has been shown that most soils contain much more potash than nitrogen or phosphoric acid. The greater part of the potash in the soil is in very insoluble and unavailable forms, and although there are large quantities present the plant may be able to use so little of it that a good crop is impossible, as has been shown by the increased yield from the use of potash on clay soils that had a high content of this element of fertility. "It has been attested that potash is of relatively less importance than either nitrogen or phosphoric acid, inasmuch as good soils are naturally richer in this element, and because a less amount is removed in general farming than of either nitrogen or phosphoric acid, as the potash is located to a less extent in the grain than in the straw, which is retained on the farm. It is, however, a very necessary constituent of fertilizers, being absolutely essential for those intended for light, sandy soils and for peaty meadow lands, as well as for certain potash-consuming crops, as potatoes, tobacco and roots, since these soils are very deficient in this element, and the plants mentioned require it in larger proportion than do others. In fact it is believed by many careful observers,—and the belief has been substantiated in large part by experiments already con-

ducted,—that the average commercial fertilizer does not contain a sufficient amount of this element. It is a particularly useful element in the building up of worn out soils, because contributing materially to the growth of the nitrogen-gathering legumes, an important crop for this particular purpose"—Voorhees.

Wood Ashes at one time was the sole source of potash for fertilizing purposes, but at present ashes supply but a very small proportion of this element of plant food. The potash in wood ashes is one of the best forms for use as a fertilizer, but the supply is so limited and the price usually demanded so high that ashes can no longer be considered as an important source of potash. Wood ashes vary greatly in composition, the ash from soft woods containing less potash than that from the hard woods; the content of potash ranging from 2 to 8 per cent.

Potash as found in wood ashes is in a form that is very soluble in water so that ashes exposed to the weather may have practically all of the potash leached out of them. Leached ashes as a rule contain less than 2 per cent of potash. As it is not possible to distinguish between leached and unleached ashes by mere physical examination it is evident that this material should be purchased only from guaranteed analysis.

In addition to potash, ashes contain from 25 to 30 per cent of lime, and in many cases, doubtless, the beneficial results obtained from ashes were as much due to the lime in them as to the potash. All ashes produced on the farm should be carefully preserved and utilized, but they can seldom be purchased to advantage.

Stassfurt Salts.—At the present time practically all of the potash used in fertilizing comes from the Stassfurt mines in Germany. These mines contain immense deposits of potash salts, and are owned by a syndicate that controls the price and output of potash the world over. A number of different minerals containing varying percentages of potash are produced from the mines, and many of them are used in Germany Only three or four of these products are in use in this country and they are the only ones that will be discussed here.

Kainite.—This is one of the crude salts which has been ground to a powder. It looks somewhat like common salt but is darker in color and contains about 12.5 per cent of potash in the form of sulphate, mixed with the sulphate and chloride of magnesia. This substance has been used because it is cheaper than the next two substances to be mentioned, but even at the lower price a ton the actual potash costs more in kainite than in the concentrated form.

Muriate of Potash is manufactured from the crude minerals of the mines by concentration, and contains about 50 per cent of potash, all of which is combined with chlorine in the form known by the chemists as potassium chloride. At the present price by the ton the muriate supplies potash at a cheaper price a pound than any of the other materials.

Sulphate of Potash is another concentrated product of the Stassfurt industry. What is known as high grade sulphate contains about 53 per cent of potash in the form of sulphate (*i. e.*, combined with sulphuric acid). The actual potash in this compound costs a trifle more a pound than in the muriate. A lower grade

sulphate containing about 26 per cent of potash mixed with sulphate of magnesia is sold under the name of "double manure salt." Although the price for a ton of this material is much less than the muriate or high grade sulphate, the cost of the actual potash is a little more.

Comparison of Potash Fertilizers.—All of the materials mentioned contain potash in forms that are soluble in water so that there is no such marked difference in availability as was noted in the case of the nitrogen fertilizers, but there is a difference in their effect on certain crops and soils due to the substances with which the potash is combined. The form in which the potash occurs in wood ashes is probably the best of all especially for use on light soils, and those which are rich in humus or are inclined to be sour; but at the prices demanded for wood ashes at the present time the potash costs more a pound than in any of the German salts.

The chlorine in the muriate has been found to be injurious to certain crops, among which may be mentioned potatoes, tobacco and sugar beets. Nearly all crops are harmed by the muriate if it is applied in large quantities immediately before or after seeding. This injury may be prevented by sowing the muriate in the fall as the potash will become fixed by the soil and the chlorine will be washed out. When the chlorine is removed in the soil water it carries with it part of the lime so that the soil in fields which are continuously manured with muriate may become sour through removal of the lime. This may be prevented of course by occasional applications of lime. The same remarks

apply to the use of kainite. As the muriate is the cheapest form of potash it is the compound that is used nearly altogether in mixed commercial fertilizers.

So far as has been determined, no injurious effect results from the use of sulphate of potash, and some experiments indicate that larger yields from a pound of potash are obtained from the sulphate than from any of the other salts. It is the only potash salt that can safely be used on potatoes, sugar beets or tobacco. Although the potash in the sulphate costs a trifle more a pound, it will probably not prove dearer in the long run, if the necessity for liming where the muriate is used is taken into consideration; so for continued use the sulphate is undoubtedly to be preferred.

Phosphatic Fertilizers.—Phosphoric acid is present in the soil in much smaller quantities than potash, and experience shows that it is much more likely to become exhausted. In fact there are sections of the country where no other fertilizers than those furnishing phosphoric acid are used, while these are bought in large quantities. All this class of fertilizers contain their phosphoric acid in the form of phosphates *i. e.*, the phosphoric acid is combined with some basic substance, which is generally lime. The phosphates may be subdivided into two general classes—the **natural** and the **manufactured phosphates.**

Natural Phosphates.—There are two general sources of phosphates—the bones of dead animals, and certain phosphate-containing minerals which will be briefly considered.

Raw Bone Meal is made by grinding raw bones to a powder, and the finer it is the more valuable the

product. This substance contains about 22 per cent of phosphoric acid and 4 per cent of nitrogen. Raw bones contain a small quantity of fat as well, and, as this prevents rapid decay of the bone, the phosphoric acid and nitrogen in the meal are somewhat slowly available to the crop.

Steamed Bone Meal.—Most of the bone meal sold at the present time is made from bones previously steamed to remove the fat, and a part of the nitrogen compounds. The fat is used in making soap and the nitrogen in glue and gelatins. Steamed bone contains from 28 to 30 per cent of phosphoric acid and about 1½ per cent of nitrogen. The steamed bones can be ground to a much finer powder, and the removal of the fat causes them to decay more rapidly so that they must be considered a more valuable source of phosphoric acid than the raw bones.

Tankage was described under nitrogenous fertilizers and is an important source of phosphoric acid in the so-called **animal fertilizers.** When the product contains a very large proportion of bone it is sometimes designated as **bone tankage,** and may contain from 7 to 18 per cent of phosphoric acid.

Bone Black or Animal Charcoal is made by heating bone in air-tight vessels until all the volatile matter is driven off, and is used in the refineries to purify sugar. After it has become spent or useless to the refiner it is sold for use as a fertilizer. Bone black contains from 32 to 36 per cent of phosphoric acid.

Mineral Phosphates.—In a number of places rock deposits are found that contain varying percentages of phosphate of lime. These phosphates are usually

named after the place where they are obtained, as, **Carolina phosphates, Florida phosphates and Tennessee phosphates.** These rocks contain from 18 to 32 per cent of phosphoric acid, and differ from the bone products in that they are purely mineral substances and contain no organic matter. Ground into a fine powder they are sometimes sold under the name of **floats**, but the rock phosphates are used only to a limited extent in the crude condition.

Superphosphates or Manufactured Phosphates.—The phosphoric acid in all of the natural phosphates

The phosphoric acid found in all fertilizers came originally from bones or from phosphate rock. The rock shown in the picture is Tennessee phosphate

described is combined with lime in a form that is extremely insoluble in water. In order to make the phosphate soluble it is sometimes treated with sulphuric acid which unites with part of the lime leaving a phosphate which contains only one-third as much lime as the natural phosphate and which is soluble in water The lime and sulphuric acid make a compound which is the same as that found in gypsum or land-plaster This combination of soluble phosphate and gypsum, made by treating the natural phosphates with acid, is

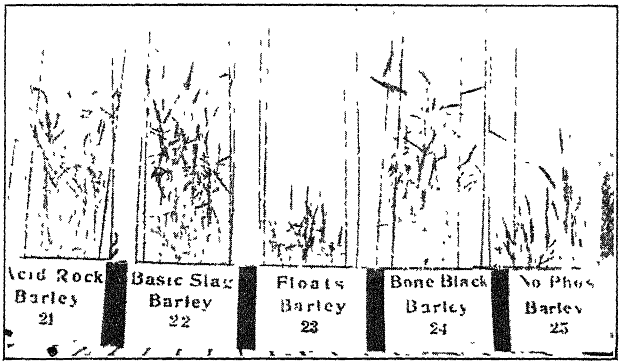
called by the various names of superphosphate, soluble phosphate, acid phosphate, acidulated rock, etc. For its manufacture the rock phosphates are generally employed both because they are cheaper and because the organic matter in the bones interferes with the use of sufficient acid to make all the phosphate soluble. A good sample of superphosphate or acidulated rock contains about 16 per cent of phosphoric acid in a form that is soluble in water.

Sometimes when insufficient acid has been used a part of the soluble phosphate will change into a form intermediate in solubility between the natural phosphate and the acid phosphate, and the phosphate is said to have undergone **reversion,** and the new compound is called **reverted phosphate.** The latter product is supposed to be more available to the plant than the insoluble or natural phosphate, hence, the soluble and reverted phosphoric acid taken together are known as the **available phosphoric acid.**

In some instances bone meal is treated with a limited amount of sulphuric acid and the product is called **acidulated bone.** This substance contains a much smaller proportion of its phosphoric acid in the soluble form than does the rock superphosphate. When soluble phosphates are added to the soil they soon combine with the mineral matter, and are converted first into the reverted phosphate, and finally into the insoluble form such as is found naturally in the soil. In this way the phosphoric acid is **fixed** and there is no danger of its being lost by leaching.

Relative Value of Phosphate Fertilizers.—The soluble phosphate present in the acidulated goods is

generally considered the most valuable form of phosphoric acid for use as a fertilizer. At first sight it seems useless to go to the expense of making the phosphate soluble when it is again rendered insoluble by the soil before the plant can make use of it. The real object in making it soluble is to aid in its distribution in the soil. When an insoluble phosphate is applied it

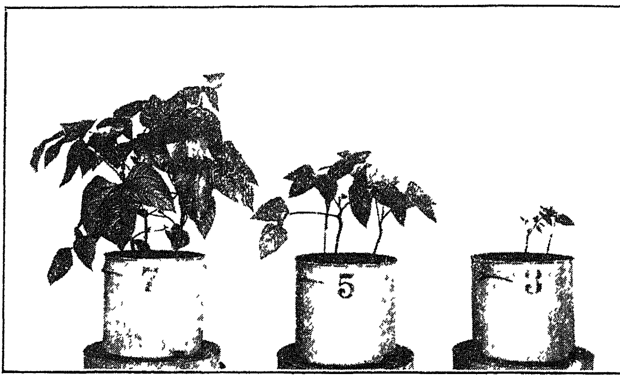


Relative availability of different phosphates. The labels on the boxes show which kind of phosphate was used

remains where it falls except for the slight distribution it receives by cultivation. In the case of the soluble phosphate, on the other hand, the phosphate dissolves in the soil water and is widely distributed before it becomes fixed by the soil. In the former case the roots must go to the phosphate while in the latter the phosphate is carried to the roots. It follows from what has been said that after the soluble phosphate is distributed throughout the soil the individual particles must be very much smaller than is the case with the

insoluble phosphate; the importance of fineness of division was clearly shown in the discussion of tillage.

There are some soils upon which the superphosphates cannot be used without injury, usually those that are deficient in lime, the superphosphate in such cases having a tendency to make them acid Indeed, it is even asserted that soils containing an abundance of lime in



Relative value of phosphate fertilizers. All pots received the same amounts of plant food, but 7 received its phosphoric acid from acid phosphate, 5 from bone meal and 3 from ground phosphate rock or "floats"

the beginning may be made acid by the continued use of superphosphate if no lime is added.

When the natural phosphates alone are considered there is no doubt that the preference should be given to those derived from bones. The organic matter present in the bones decays when it is incorporated with the soil, and this process doubtless causes the phosphate to become more readily available to the plant, while the rock phosphate on the contrary is very

slowly decomposed The degree of fineness to which bone meal or mineral phosphate is ground is of prime importance. Very fine bone meal is much more available than that which is coarser and is always rated at a higher price a ton.

Using Floats With Manure.—The use of floats, or finely ground phosphate rock, has not met with general favor, and it probably does not give good results when used alone Some of the earlier experiments indicate that it has practically no value as a source of phosphoric acid for the plant Recent investigations at the Ohio and Illinois Experiment Stations show that when floats is added to farm manure it has a very high fertilizing value; in fact the increased crop production in Ohio due to adding the ground rock phosphate to the stall manure was nearly as large as that obtained from the addition of superphosphate The acid substances produced during the decay of the manure apparently make the phosphoric acid in the rock more available, and it would seem from these experiments that the comparatively inexpensive floats might, partially at least, replace superphosphate if used in connection with the manure. Other experiments have demonstrated that good results can be obtained from the use of ground rock phosphate, when plowed under with a green manure crop like clover, but that it is of very little value if used on a soil low in organic matter In a plot experiment at the Massachusetts Experiment Station two "equal money's worth" of ground Carolina rock and superphosphate were compared. In this case the superphosphate proved superior at first, but within a few years the plot to which rock phos-

phate was added gave higher yields. It would seem, on the whole, that the use of floats with manure is worthy of a trial by anyone needing a phosphate fertilizer. Ohio Bulletin 134, recommends that the ground rock be used "as an absorbent in the stable, thus securing an intimate mixture with the manure in its fresh condition."

CHAPTER XIX

MIXED FERTILIZERS

Complete Fertilizers.—Mention was made of the fact that the basic materials described in the foregoing sections contain only one, or at most two, of the essential elements of fertility. By far the larger part of the commercial fertilizers used by the farmers in this country are purchased in the form known as **complete fertilizers.** A complete fertilizer, in the sense in which the word is used in trade, is one that contains nitrogen, phosphoric acid and potash, in proportions that are supposed to be suited to the requirements of farm practice. Practically all of these fertilizers are made by mixing two or more of the basic materials heretofore described, the different ingredients being so combined as to give the desired percentage of nitrogen, phosphoric acid and potash. In case the basic materials alone yield a product that is richer in the essential ingredients than is desired by the manufacturer, sufficient gypsum, dry earth, peat or other inert matter is added to bring the percentage of these ingredients down to the desired point. Materials added in this way are known as **fillers.*** These fertilizers are indiscrim-

* There is a mistaken notion which is quite prevalent that anything contained in a fertilizer except nitrogen, phosphoric acid and potash is a filler. As a matter of fact it is impossible to make any rational combination of the basic materials which will contain more than one-third of its total weight of the three "essential ingredients," for even in the

inately recommended for general use and all sorts of startling claims are made for them by the various manufacturers. They are offered as universal fertilizers, irrespective of the well known fact that soils differ widely in their characteristics and that the crops vary in their food requirements. To be sure, a fertilizer of this kind if sufficiently rich in nitrogen, phosphoric acid and potash might be made to produce a large yield on any kind of soil if used in quantities, but such a use of a fertilizer would result in adding some of the elements at least in amounts far in excess of the need of the crop. The profits of ordinary farming are not sufficient to warrant the application of any of the elements of plant food in larger quantities than is required by the plant. An economical use demands that fertilizers be adapted to the soil, and to the crop to be raised, and this end can rarely be attained by the use of complete fertilizers. A little thought on the part of the farmer will convince him that the use of these general fertilizers is irrational, and that to obtain the best results he must adopt some system of fertilization especially adapted to his particular conditions.

Special Fertilizers.—A large number of so-called special fertilizers now offered by the manufacturers are supposed to be adapted to the particular needs of a special crop or class of crops. Each fertilizer usually bears the name of the particular crop for which it is designed. Such fertilizers are offered for all of the

highest grade materials the nitrogen, phosphoric acid and potash are combined with other substances. A filler properly speaking, is a substance added for the express purpose of diluting the fertilizer and usually contains no plant food whatever. No filler is used in the highest grade mixed goods.

prominent crops. There are found on the market, corn specials, tobacco specials, potato specials, trucker's favorite, etc , etc., many manufacturers offering a number of such products.

If such fertilizers were compounded with any regard to the requirements of the particular crop for which they were advocated their use would be a distinct advance over the use of the general complete fertilizers. Unfortunately their chief claim is in their attractive names, and their composition is rarely in accord with what scientific investigation has shown to be necessary for the crop. That these mixtures are not based on any scientific knowledge of the needs of the plant is shown by the fact that the specials offered for the same crop by the different manufacturers vary as widely in composition as do the fertilizers offered for different classes of crops. Yet these several makers are all claiming to have the best fertilizer for that particular crop. A recent bulletin giving the guaranteed analysis of the fertilizers offered for sale in the State of Ohio contains some data on this subject, and as the conditions in other states are undoubtedly similar, it may be interesting to call attention to a few facts brought out by an examination of this bulletin Forty-four of the fertilizers on the list are especially recommended for potatoes under such names as, Potato Grower, Potato Special, Potato and Tobacco Special, etc. These specials are widely variable in composition as is shown by the following table which gives the guaranteed analysis of seven of them, selected to show the variation in per cent of ammonia, phosphoric acid and potash.

Number	Ammonia per cent.	Phos. Acid per cent.	Potash per cent.
1	2	10	4
2	1	10	4
3	3	10	6
4	1	6	10
5	1	8	6
6	2	7	6
7	1	12	6

In view of such a lack of uniformity in composition, the farmer who places his dependence on these special fertilizers, must be at a loss to know which one to select. The general experience of farmers in the Eastern states where fertilizers have long been used on potatoes, indicates that the best combination for this crop is one that contains potash in excess of the phosphoric acid. Voorhees recommends a mixture containing nitrogen 3 to 4 per cent, phosphoric acid 6 to 8 per cent, and potash 8 to 10 per cent. In spite of this fact only four out of the forty-four specials mentioned above contain potash in amounts exceeding the phosphoric acid. And lastly, two-thirds of the special potato fertilizers contained potash in the form of muriate. The authorities are practically all agreed that the muriate is injurious to the potato, and that all the potash used on this crop should come from the sulphate, and yet only one-third of these fertilizers under discussion contained potash in this form. Similar discrepancies are found in the special fertilizers offered for crops other than the potato. These facts are sufficient to convince one that little dependence can be placed upon the name under which a fertilizer is

sold. Even were this idea of special fertilizers for each crop carried out consistently it does not take into account the fact that soils are very different in their fertilizer requirements for the same crop, and that a given crop may fail in one place for lack of nitrogen while the failure in another case may result from an insufficient supply of phosphoric acid or potash. These special fertilizers militate against progressive farming, for the farmer who uses these mixtures is too apt to place his reliance upon them instead of intelligently studying the needs of his own soil and crops, without which study no use of fertilizers will long be successful.

High and Low Grade Fertilizers.—As the basic materials show great variation in the amounts of fertilizing ingredients they contain, it will readily be seen that products made by mixing these materials will contain very different percentages of nitrogen, phosphoric acid and potash. If dried blood, steamed bone meal and muriate of potash were used, for instance, the fertilizer would have a high content of the three essential elements, while if low grade tankage and wood ashes or kainite were employed the product would have a much lower percentage of the three named substances. The use of a filler as well makes it possible to have an almost endless variety in the composition of fertilizers, and hundreds of different brands are offered in the market. It is customary to designate those having large amounts of plant food as **high grade goods** and those low in plant food as **low grade.** While no hard and fast line can be drawn between high and low grade goods it may be said that any complete ferti-

lizer that contains less than two per cent of nitrogen should be considered low grade.

The terms, high grade and low grade, are used by some writers to distinguish the condition of the plant food in the fertilizer and not the amount. Leather meal, therefore, would be classed as low grade because the nitrogen in it is in an unavailable form although the amount is relatively high. It may be stated as a general rule that the fertilizers containing the largest amounts of plant food usually have it in the most desirable condition, while the materials containing the toughest forms of plant food are used to make the cheaper fertilizers

Expensiveness of Cheap Fertilizers.—A large part of the commercial fertilizers used by the farmers at the present time is purchased in the form of cheap mixed or complete fertilizers The low price is attractive, and, to many people a fertilizer is a fertilizer, irrespective of its composition. Consequently this class of goods is sold more readily than those of a higher price, although the plant food in the cheap fertilizers actually costs more a pound. This fact is very clearly set forth in a recent bulletin of the New York Experiment Station from which the table following has been adapted. The analyses of all the fertilizers sold in the State have been compiled, along with the retail prices, and from these data the price a pound paid for nitrogen, phosphoric acid and potash in the different grades of goods has been calculated.

The fertilizers have been divided into four classes as follows: (1) Low grade having a commercial valuation of less than $16 a ton; (2) medium grade from $16

to $20; (3) medium high grade, from $20 to $25; (4) high grade over $25 For the sake of comparison a few of the basic materials are included in the table.

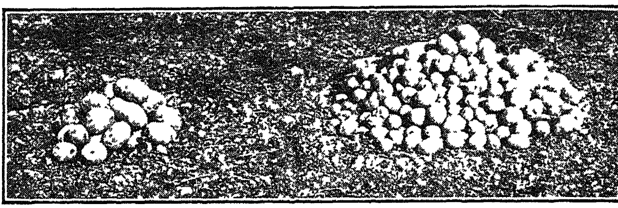
AVERAGE COST OF ONE POUND OF PLANT FOOD TO CONSUMERS

	Nitrogen cents	*Phos Acid cents*	*Potash cents*
Low grade complete fertilizers	26.3	8.0	6.8
Medium grade complete fertilizers	23.2	7.0	6.0
Medium high grade complete fertilizers	21.0	6.4	5.4
High grade complete fertilizers	19.6	6.0	5.0
Dried blood	18.5	...	...
Bone meal	14.9	3.96	...
Nitrate of Soda	13.9	..	...
Acid phosphate		5.1	...
Sulphate of potash	.	.	5.0
Muriate of potash	..		4.6

It will be seen that the price a pound of plant food is very much less in the high grade goods than in the low grade. If the fertilizer is to be shipped any distance there is another point in favor of the high grade goods for it costs no more for freight on a ton of a high priced fertilizer than on a ton of a low priced one, while the former may contain twice as much plant food as the latter.

Home Mixed Fertilizers.—The above table not only shows that plant food is cheaper in high grade fertilizers than in low grade, but also that the essential elements can be purchased more cheaply in the basic materials than in any mixed fertilizer. This is due to the fact that the manufacturer must be paid for

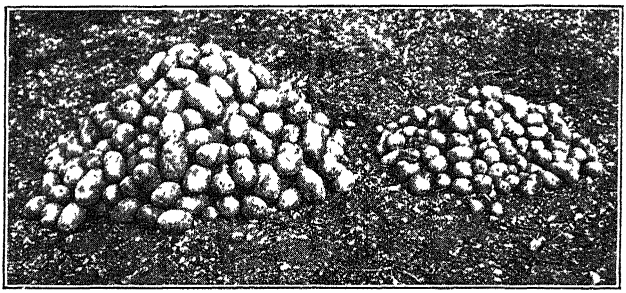
mixing, bagging, etc. Voorhees has shown by careful investigation that the average charges of the manufacturer for this work amount to $8.50 a ton. In other words, the plant food in one ton of a mixed fertilizer can be purchased by the farmer for from $6 to $10 less in unmixed materials. This fact suggests the thought that it might be possible for the farmer to buy the basic materials and prepare his own mixed fertilizers. The matter of home mixtures has been carefully studied by a number of experiment stations and it has been shown conclusively that the materials can



Potatoes grown without fertilizers. The small pile on the left only is marketable

be evenly mixed on the farm, that the mechanical condition is good, and that the results obtained from their use are entirely satisfactory. It would not be advisable to try to make the superphosphate on the farm, but the plain rock-superphosphate can be purchased to mix with the other materials. There are some obvious advantages other than cheapness in home mixing over the purchase of mixed fertilizers. The usual analysis of a mixed fertilizer gives no clue as to the condition or source of the nitrogen, and it is difficult to determine its availability, while in the home made mixture the condition of the nitrogen should always be known.

Home mixing permits the uniting of the different elements in the proportions which have been found to meet the requirements of the crop best and the soil on which it is to be raised, something that is not easily managed with factory mixed fertilizers. By buying the basic materials separately it is possible to apply the different elements at different times, a point that is sometimes of great advantage in feeding a crop, especially if it is one that needs large quantities of nitro-

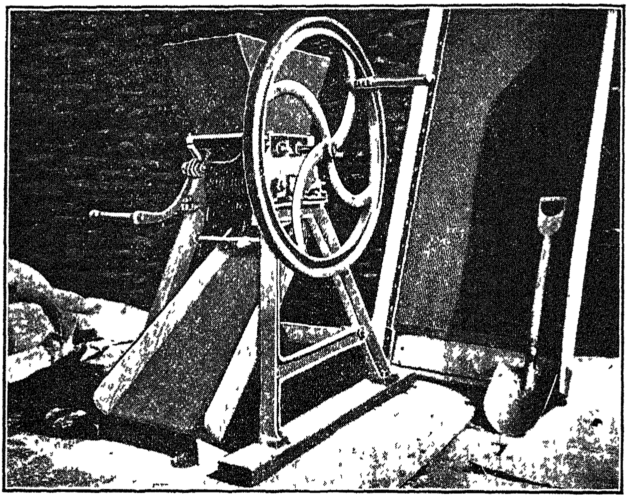


Potatoes with complete fertilizer. Marketable potatoes on the left. Compare with cut on opposite page. Fertilizers not only increase the yield, but improve the quality as well

gen. In fact the only advantage that can consistently be claimed for the mixed goods is that they are more generally distributed in the market than the basic materials and can, therefore, be more easily purchased in such amounts and at such times as are convenient.

The conditions existing upon the majority of farms are such that an elaborate arrangement, even for mixing small quantities at a time, will not be brought into use, and a tight barn floor and square pointed shovel will be the only requisites at disposal. Under such

circumstances after weighing out the quantities to be mixed they should be spread upon the floor in layers one upon the other. Then beginning at one side and working across, the whole should be shoveled over, this may be leveled somewhat and the operation re-



An outfit for the home mixing of fertilizers. The grinding machine is necessary if the materials are lumpy, but if they are fine the screen and shovel alone are needed

peated until the mixing is satisfactory. In addition to the shovel and the barn floor a large screen such as is used in screening gravel or coal ashes, may be employed with decided advantage; the material at the first can be thrown upon the screen and by this means lumps may be separted and more easily broken up and the thoroughness of the mixing will be increased.

CHAPTER XX

USING COMMERCIAL FERTILIZERS

Fertilizers are used primarily in order to obtain an increased profit through the larger yield of the crop to which they are applied From what has already been said, it must be evident that the fertilizer to be used depends on the soil and the particular crop to be raised An economical and profitable use of commercial fertilizers calls for much more thought and study than the farmer has been accustomed to devote to the subject, for until he has a fair knowledge of the nature of his soil and the requirements of the crop he desires to produce he is not prepared to use good judgment in the selection of his fertilizing materials Every farmer should conduct certain experiments on his own soil to ascertain what substances give the best results, but the majority of them are loath to undertake these experiments and prefer to follow some more general system (or lack of system) in the use of fertilizers. Commercial fertilizers have been on the market for a sufficient length of time to have been widely employed and as might have been surmised there have been developed a number of different plans or systems for their use which vary somewhat in the principles on which they are based, and which will be discussed briefly.

Ville System.—"The one which has perhaps received the most attention, doubtless largely because

one of the first presented, and in a very attractive manner, is the system advocated by the celebrated French scientist, George Ville. This system, while not to be depended upon absolutely, suggests lines of practice which, under proper restrictions, may be of very great service. In brief, this method assumes that plants may be, so far as their fertilization is concerned, divided into three distinct groups. One group is specifically benefited by nitrogenous fertilization, the second by phosphatic and the third by potassic. That is in each class or group, one element more than any other rules or dominates the growth of that group, and hence each particular element should be applied in excess to the class of plants for which it is a dominant. In this system it is asserted that nitrogen is the dominant ingredient for wheat, rye, oats, barley, meadow grass and beet crops. Phosphoric acid is the dominant fertilizer ingredient for turnips, Swedes, Indian corn (maize), sorghum and sugar cane; and potash is the dominant or ruling element for peas, beans, clover, vetches, flax and potatoes. It must not be understood that this system advocates only single elements, for the others are quite as important up to a certain point, beyond which they do not exercise a controlling influence in the manures for the crops of the three classes. This special or dominating element is used in greater proportion than the others, and if soils are in a high state of cultivation, or have been manured with natural products, as stable manure, they may be used singly to force a maximum growth of the crop. Thus, a specific fertilization is arranged for the various rotations, the crop receiving that which is the

most useful. There is no doubt that there is a good scientific basis for this system, and that it will work well, particularly where there is a reasonable abundance of all the plant food constituents, and where the mechanical and physical qualities of soil are good, though its best use is in "intensive" systems of practice. It cannot be depended upon to give good results where the land is naturally poor, or run down, and where the physical character also needs improvement."

Wagner System.—"Another system which has been urged, notably by German scientists, is based upon the fact that the mineral constituents, phosphoric acid and potash, form fixed compounds in the soil, and are, therefore, not likely to be leached out, provided the land is continuously cropped. They remain in the soil until used by growing plants, while the nitrogen, on the other hand, since it forms no fixed compounds and is perfectly soluble when in a form useful to plants, is liable to loss from leaching. Furthermore, the mineral elements are relatively cheap, while the nitrogen is relatively expensive, and the economical use of this expensive element, nitrogen, is dependent to a large degree upon the abundance of the mineral elements in the soil. It is, therefore, advocated that for all crops and for all soils that are in a good state of cultivation, a reasonable excess of phosphoric acid and potash shall be applied, sufficient to more than satisfy the maximum needs of any crop, and that the nitrogen be applied in active forms, as nitrate of soda, and in such quantities and at such times as will insure the minimum loss of the element and the maximum development of the plant. The supply of the mineral elements may

be drawn from the cheaper materials, as ground bone, tankage, ground phosphates and iron phosphates, as their tendency is to improve in character; potash may come from the crude salts. Nitrogen should be applied as nitrate of soda, because in this form it is immediately useful, and thus may be applied in fractional amounts, and at such times as best meet the needs of the plant at its different stages of growth, with a reasonable certainty of a maximum use by the plants. Thus no unknown conditions of availability are involved, and when the nitrogen is so applied, the danger of loss by leaching, which would exist if it were all applied at one time is obviated."—Voorhees.

System Based on the Analysis of Plant.—Still another system is based on the food requirements of the plant, as shown by the analysis of the plant itself. The amount of plant food removed from each acre of ground is calculated from the analysis of the plant and a corresponding amount is returned to the soil. Different formulas are, therefore, recommended for each crop, and in these the nitrogen, phosphoric acid and potash are combined in the proportions in which they are found in the plant. Experience shows that it is necessary to add amounts of these fertilizers to the soil that will supply more plant food than is removed by the crop if the maximum results are desired. This system may result in a large yield but cannot be considered an economical method of feeding the plant, as one or more of the elements is likely to be applied in excess of the requirements of the crop. It does not take into consideration, for instance, the fact that a plant which contains a large amount of one element

of plant food may possess unusual power of procuring that element from the soil. The principle underlying this system of course, is the idea that to maintain the fertility of the soil unimpaired an amount of plant food equivalent to that removed by the crop must be returned to the land. To this extent the system is similar to the use of barnyard manure but is not so effective.

Fertilizers Applied to Money Crops.—Another system used in ordinary or extensive farming is to apply all the fertilizer to the money crop in a rotation. This method is used especially where only one crop in a rotation is sold, the others being fed on the farm. A liberal supply of food is used to give the maximum yield which the climate and season will permit. The amount of food applied is in excess of the requirements of the crop and the residue is depended upon to help nourish the succeeding crops, or at least the one immediately succeeding the money crop. This system has some valuable features and is probably the one most in use in this country at the present time.

Irrational System.—Too frequently fertilizers are used by what certain writers call the **hit or miss system.** No special thought is given to the requirements of the crop or the composition of the fertilizer, but if the farmer feels that he can afford it and the agent is a glib talker, the sale is made. If the buyer happens to hit the food requirements of his crop a profit is secured and he is correspondingly happy, while if he makes a miss he feels assured that there is no value in commercial fertilizers.

Weak Points in These Systems.—All of these systems, with the exception of the last one mentioned, have their good features and have proved remunerative in the hands of many of their advocates. They all have, however, one weak point in common, *i. e.*, they do not take into consideration the fact that different soils contain varying amounts and proportions of plant food, and that while a certain soil may be lacking in potash, for instance, it may contain amounts of nitrogen and phosphoric acid sufficient for a maximum yield. Such a soil would obviously be benefited by an application of potash, while nitrogen and phosphoric acid would produce no effect. Experiments have shown that on ordinary soils it seldom happens that all three of the elements of fertility are required at one time. Unfortunately there is no easy way of determining accurately the fertilizer requirements of a soil for a particular crop. Van Slyke has formulated the following general rules which may be of value where no accurate data are at hand.

Growing Crop Should Be Studied.—"It is impossible to give any fixed rules which will cover all cases and enable a farmer to tell without any experiment on his part what food constituents his soil lacks. In a general way, the crops themselves may give some valuable suggestions.

1. As a rule, lack of nitrogen is indicated, when plants are pale-green, or when there is small growth of leaf or stalk, other conditions being favorable.

2. A bright, deep-green color, with a vigorous growth of leaf or stalk, is, in case of most crops, a sign that nitrogen is not lacking, but does not neces-

sarily indicate that more nitrogen could not be used to advantage.

3. An excessive growth of leaf or stalk, accompanied by an imperfect bud, flower, and fruit development, indicates too much nitrogen for the potash and phosphoric acid present.

4. When such crops as corn, cabbage, grass, potatoes, etc., have a luxuriant, healthful growth, an abundance of potash in the soil is indicated; also, when fleshy fruits of fine flavor and texture can be successfully grown.

5. When a soil produces good, early maturing crops of grain, with plump and heavy kernels, phosphoric acid will not generally be found deficient in the soil.

Such general indications may often be helpful, and crops should be studied carefully with these facts in mind."

Field Experiments to Determine Fertilizers Needed.—All the methods so far suggested for determining the kind of fertilizer to be used are open to objection because of the large element of uncertainty involved. It has been repeatedly pointed out that individual fields differ in their power to supply the crop with plant food even when the respective soils are very similar in appearance. None of the plans described provide for any control experiment to show whether the use of the fertilizer has been really profitable. The only rational way of ascertaining the proper fertilizing material to use on a given field is to compel the soil itself to answer the question. This can be done by a set of simple and easily conducted field experiments which every one should conduct on his own

farm. These experiments consist simply in dividing a small portion of the field into small plots on each of which a different kind of fertilizer is used, the yield being compared with check plots to which no fertilizing material has been added. The different crops vary in their power to extract plant food from the soil, consequently, these experiments should be conducted with the particular crop or crops on which the fertilizer is to be used.

Conducting The Experiment.—The first important consideration in an experiment of this kind is the selection of the location for the plots. The spot selected should represent as nearly as possible the average condition of the entire field The soil should be uniform in quality over the entire area devoted to the experiment so that one may feel sure that any difference in yield from the several plots is not due to variation in the composition of the soil. Plots 1 rod wide and 8 rods long (containing one-twentieth acre) will be found a convenient size for the purpose, but any other size could be used. The simplest experiment which will give any reliable information calls for a row of at least seven such plots, with a space of at least 3 feet between each plot. The ground is first plowed and harrowed and then the plots are measured out, each corner being marked by a stake driven well into the ground. The fertilizers for each division are mixed and applied by hand, care being used not to scatter the material beyond the plot, for which it is intended. The diagram shows the arrangement of the plots and the kind and quantity of fertilizing material to be used on each.

The plots may be seeded separately but it saves labor and gives practically as good results if they are planted with the remainder of the field In any case the seeder must be run lengthwise of the plots so as to

No Fertilizer
15 lbs. Nitrate of Soda **15 lbs. Sulphate of Potash** **30 lbs. Acid Phosphate**
30 lbs. Acid Phosphate **15 lbs. Sulphate of Potash**
No Fertilizer
15 lbs. Nitrate of Soda **15 lbs. Sulphate of Potash**
15 lbs. Nitrate of Soda **30 lbs. Acid Phosphate**
No Fertilizer

avoid dragging any of the fertilizer from one plot to another.

Harvesting the Crop.—The area devoted to the experiment should receive exactly the same treatment during the growing season as the rest of the field, except that in no case is cross cultivation of the plots

allowable. In case of corn, for instance, the cultivator could be run lengthwise of the plots but any cultivation in the other direction would have to be done with the hoe to avoid carrying any of the fertilizers on the other plots. In many cases it is not even necessary to harvest the crop on the several divisions separately, for the difference in the plots is so marked that it will be apparent to the eyes. Generally, however, it is desirable to harvest and determine the yield from each plot. If the crop is one which is planted in rows and inter-tilled it will be best to harvest the same number of rows from the middle of each division, discarding the outer rows as well as those on the spaces between the plots. In the case of small grains or hay crops, the best procedure is as follows: Stretch a cord around each plot from stake to stake, now cut away the growth for a small space around the experimental area and in the intervening spaces. This leaves each plot standing out distinctly so it can be readily observed and the crop easily harvested. The weight of both grain and straw from each plot should be determined.

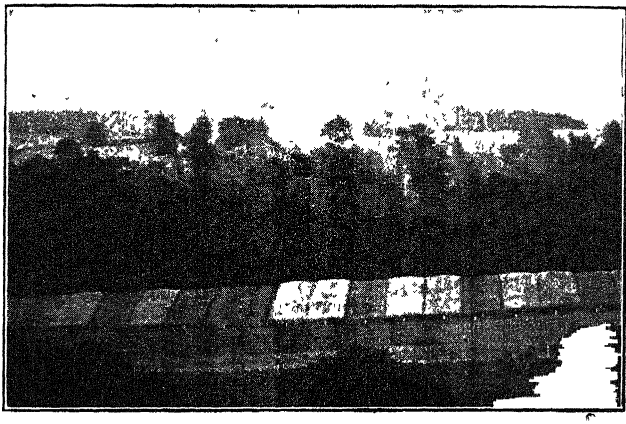
Interpreting the Results.—The yield from each of the three check plots should be practically the same. If this is the case it shows that the soil in the area devoted to the experiment is uniform in character. Any great difference in the checks invalidates the experiment as it then would be impossible to determine if the variation in the plots was due to the fertilizer added or to a difference in the composition of the soil. A little thought will enable one to decide from the experimental data what elements of fertility gave satisfactory results with the crop and soil under investigation.

If the yield on all the plots, was practically the same, for instance, it would be evident that no beneficial results could be expected on that soil from the use of commercial fertilizers. If plot number 2 gave higher results than any of the others it would indicate that nitrogen, phosphoric acid and potash were all required. If plots 2, 3 and 6 gave larger yields than the checks and 5 did not it would suggest that phosphoric acid alone was necessary. An increased yield on 2, 3, and 5 but not on 6 indicates need of potash. A larger crop on 2, 5 and 6 but not on 3 shows need of nitrogen. A large increase in yield over the checks on 2 and 6 and a smaller increase on 3 and 5 suggest that both nitrogen and phosphoric acid are beneficial but potash is not; and so on.

In case the person conducting a series of experiments of this kind feels in doubt regarding the proper interpretation of the results, he will find the Agricultural Colleges and Experiment Stations ready to assist him if he will submit his data to them.

More Extensive Experiments Desirable.—An experiment such as that described should be conducted for several years in succession in order to obtain very reliable data as to the fertilizer requirements of a soil. Some peculiarity of climatic conditions or other factors might cause variations in yield one year which could not be repeated; hence the result of an experiment of only one year's duration must be regarded as merely suggestive and not final in the answer to the questions propounded. The test described includes the minimum number of plots, and several more could be added to advantage if more comprehensive data are

desired. It would be a decided improvement to add three plots on which nitrogen, phosphoric acid, or potash alone was used. Much useful information could also be gained by having additional plots for (1) barnyard manure, (2) lime, (3) lime and manure; (4) nitrogen, phosphoric acid, potash and lime; (5) floats



A bird's-eye view of some fertilizer test plots. Such plot tests are the only accurate means of determining the fertilizer requirements of the soil

and manure, etc. Some authorities suggest adding lime to one end of all the plots but on the whole it seems more desirable to have separate plots for the lime experiments. Whatever the number of tests, there should be a check about every third plot to insure the uniformity of the soil in the area used for the experiment. In many states the Experiment Stations are willing to co-operate with the farmer in tests of this kind provided he will conduct the experiment carefully, and furnish the station with a complete report.

In any case, the colleges and experiment stations are always glad to help in planning and carrying out the experiments as well as interpreting the results

Field Tests Only Reliable.—There cannot be too much emphasis placed on the statement that field tests are the only means of obtaining reliable information regarding the plant food required by a crop on a given soil. Chemical analysis of the soil, or the soil water, have been suggested as a means of determining the proper fertilizer to use, and from time to time various methods of making tests in small pots or baskets have been recommended, but as it remains to be demonstrated that the results of these tests bear any relation to those obtained in the field, no dependence can be placed on these methods. The only rational practice in the use of commercial fertilizers is one that is based on the results of field tests. It does not follow from this statement that no profit will result from a less intelligent use of fertilizers, but it is certain that a definite knowledge of the requirements of the crop, and the soil are necessary to obtain the most profitable increase in yield.

Commercial Fertilizers Not All-Sufficient.—Absolute dependence should not be placed on commercial fertilizers alone to maintain the fertility of the soil. Their continued application without the use of any other method of improving the soil will eventually result in serious injury to its physical condition. Commercial fertilizers add little or no humus to the soil, and to obtain the best results it is absolutely necessary to provide humus, either by plowing under green crops or by the use of barnyard manure. Numerous experi-

ments have shown that commercial fertilizers give much better returns when used in connection with barnyard manure than if used alone, and they are coming into use in this manner more and more as the subject is more thoroughly investigated

It may be said here that commercial fertilizers are not merely stimulants as is frequently imagined, but that they actually supply plant food, and if rationally used will leave the soil more fertile than before their use instead of decreasing its fertility, as would happen if a mere stimulant were used. On the other hand there can be no doubt that as commonly employed the effect of commercial fertilizers is to deplete the fertility of the soil more completely than would be possible without their use. Notwithstanding this fact, commercial fertilizers have an important place in the rural economy, but they should not be used to do the work that can be better accomplished by properly husbanding the home resources.

CHAPTER XXI

BUYING COMMERCIAL FERTILIZERS

Fertilizer Laws and Guarantees.—It is impossible for the farmer to determine the kind and proportion of the different materials entering into the composition of a fertilizer by its appearance, weight, smell or any physical examination. Formerly all commercial fertilizers were sold without any guarantee of their composition. The injustice done to the purchaser under such a system, has resulted in the passage of laws, in most States, which require the manufacturer, or dealer, to give the actual amounts of the different constituents contained in these products. The manufacturers are compelled to guarantee the percentage of nitrogen (or ammonia), available phosphoric acid, and potash that each brand contains, and usually the composition must be stated on each bag or parcel of the fertilizer that is offered for sale. The enforcement of this law, and the chemical examination of the fertilizers to determine if they agree with the guarantee, are entrusted to the Experiment Stations in some States, while in others they are in the hands of the State Department of Agriculture. The results of the analyses of the various brands are published in bulletins for free distribution, and these should be generally consulted by the farmers using fertilizers. One result of the fertilizer laws has been greatly to reduce the number of brands offered

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for sale, and the decrease has fallen in a great measure on the low grade goods, as the worthlessness of a large number of such brands has been exposed by chemical analysis.

Guarantees are Often Confusing.—The only constituents that should be taken into consideration in the purchase of a mixed fertilizer are nitrogen (or ammonia), available phosphoric acid, and potash. These must be stated in the guarantee, and the fertilizer laws are so well enforced in most States that the buyer is safe in assuming that he will receive the guaranteed amount of these three constituents. The laws, however, do not prevent the use of other statements on the bags. The result is that in many cases superfluous words and reiterations are used, apparently with the intent of confusing the purchaser. **Phosphoric acid 10 per cent,** for instance, is often stated as **equivalent to bone-phosphate 22 per cent,** whether the phosphoric acid actually comes from bone or from rock phosphate. The unwary consumer sees the larger figure, 22 per cent, and is led to believe that he is obtaining something more than the 10 per cent of phosphoric acid which is all that is guaranteed. Potash, likewise, is often stated as **equivalent to sulphate of potash,** whether or not the sulphate is used in its manufacture. The following example taken from the label on a brand of fertilizer on the market illustrates this point.

The only point of interest to the buyer in this statement of analysis is the per cent of nitrogen (or ammonia), available phosphoric acid, and potash. In the state in which this fertilizer was found on sale, am-

GUARANTEED ANALYSIS

	Per cent
Nitrogen	.82 to 1
Equivalent to ammonia	1 to 2
Available phosphoric acid	8 to 10
Equivalent to available bone phosphate	18 to 22
Total phosphoric acid	9 to 12
Equivalent to bone phosphate	25 to 30
Potash actual	2 to 3
Equivalent to sulphate of potash	3 5 to 5

monia is guaranteed instead of nitrogen As the dealer is held liable only for the lowest amounts stated in the guarantee, this statement, when shorn of its redundant expressions would read as follows:

	Per cent
Ammonia	1
Available phosphoric acid	8
Potash	2

Consult the Control Bulletin.—In buying fertilizers as in the purchase of other commodities it is desirable to get the highest possible return for the money invested. It has been pointed out that more plant food can be obtained for the money in the unmixed basic materials than in any kind of mixed fertilizers, but in spite of this fact there are undoubtedly large numbers of persons who will continue to buy mixed goods for years to come. The attention of such persons is again called to data given on page 215, showing the relative cost of plant food in high and low grade fertilizers. Whatever form is used the fertilizer should be purchased only on the basis of its analysis as shown by the bulletin from the control laboratory, or

in case this is impossible, on the basis of the lowest amounts of nitrogen (or ammonia), phosphoric acid and potash which it is guaranteed to contain. In many States the bulletins referred to give in addition to the analysis the **calculated trade value or commercial valuation.** This in most instances represents what would be the actual cost of the amount of the three valuable ingredients of the fertilizer, if they were purchased for their average retail trade price. Where such a table is available the farmer will do well to consult it before making his purchase, and in general terms it may be said that he should never pay for a mixed fertilizer very much in excess of the price a ton given in the commercial valuation.

Calculating the Commercial Value of a Fertilizer.—The purchaser, in the majority of instances, should be governed in the price he pays for a fertilizer by the valuation placed on it by the control station. In some states this valuation is not given, or the prospective buyer may not be in possession of the bulletin. In this case the commercial value of the fertilizer may be calculated easily from the guaranteed analysis. First determine the number of pounds of nitrogen, available phosphoric acid, and potash, in a ton of the fertilizer. Then multiply by the value a pound (15 cents for nitrogen and 5 cents each for phosphoric acid and potash), and the sum of the results so obtained will be the retail value of the crude material used in the fertilizer. A simple method which will give very nearly the commercial valuation of a fertilizer is to multiply the percentage of ammonia by two and one-half, add the product to the percentages of available phosphoric acid

and potash, and the result will be the commercial value of a ton of the fertilizer in dollars and cents.

Example.—The fertilizer mentioned above is guaranteed to contain 1 per cent of ammonia, 8 per cent of available phosphoric acid and 2 per cent of potash. Multiplying 1 by 2.5 gives 2.5. To this add 8 and 2 and the result is 12.50, which means that the commercial value of the fertilizer is $12.50 a ton. In case the analysis states nitrogen instead of ammonia the nitrogen should be multiplied by 3, and added to the available phosphoric acid and potash. The valuation determined in this way should be compared with the selling price of the fertilizer, and the difference should never exceed $5 a ton. It is of interest to note that the fertilizer mentioned in the example retailed for $21 a ton This is an excess of $8 50 over the cost of the crude materials, which is just the average cost of mixing, etc, as determined by Voorhees (see page 216). In calculating the value of the fertilizer the buyer must shut his eyes to everything but the lowest guaranteed per cent of the three essential ingredients, and must not allow himself to be confused by any statements of **equivalents.**

Unit Basis of Purchase.—In commercial transactions most of the quotations of the crude materials used in the manufacture of fertilizers are based on the **unit.** A unit means 1 per cent on the basis of a ton, or 20 pounds. For example a unit of available phosphoric acid would be 20 pounds, and if the quotation was $1 a unit the phosphoric acid would cost 5 cents a pound. This system is applied to the sale of nitrate of soda, the potash salts, blood meal, tankage, superphosphate,

etc. In nitrogenous goods the price is usually stated at so much a unit of ammonia. This system, all things considered, is the most satisfactory to both purchaser and dealer, as the one gets exactly what he pays for, and the other is paid for all he delivers. The number of units in the material is determined by chemical analysis. At the present time this system is rarely used in the sale of mixed goods, but there is no reason why it should not be applied to these as well as to the unmixed materials.

Names of Fertilizers Sometimes Misleading.—There is no doubt that in many cases an attractive name plays an important part in the sale of a fertilizer. Unfortunately the brand name of a fertilizer is not necessarily any indication of its composition. An instance in this connection is the abuse of the word, **bone,** by the fertilizer manufacturers. They are fully aware that the average farmer favors bone as a source of phosphoric acid, and as a consequence that word often appears in the brand name when it should not. There are licensed in a certain State over 100 fertilizers with the word, bone, occurring in the brand name, which either have none of the phosphoric acid derived from bone, or have at least a part of the phosphoric acid in the form of rock phosphate. Others are called **humus fertilizers,** when they contain practically no organic matter, which is the only source of humus. These facts emphasize the statement that the buyer should carefully study the bulletin from the control station, and base his purchase wholly on the cold facts therein stated. It may be said in passing that there is a movement on in several states to revise the ferti-

lizer laws so as to compel the maker of fertilizers to state the materials entering into the composition of a brand, as well as its content of the three essential ingredients. Such a law if possible of enforcement would be a distinct advance over the present system.

Cooperative Buying.—Money can always be saved by buying large quantities, for the dealers are justified in giving better prices on large lots, and as a rule better freight rates can be secured Where a number of farmers in a community are using the same kind of goods it will be to their advantage to buy cooperatively through the granges or farmers' clubs. The crude materials especially can be bought more cheaply in this way. In some places, a certain mixture has been found to be satisfactory by a number of farmers, and they have the goods mixed by a manufacturer in accordance with their own specifications calling for a certain formula and specific ingredients. This method usually gives better results than the indiscriminate purchase of the so-called **standard brands.** As a general rule it may be said that, taking the precaution to compare the commercial valuation and the selling price, it is always wise to purchase high-grade fertilizers.

Trade Values not Agricultural Values.—The values for commercial fertilizers and manures which have been discussed are trade values, and do not necessarily bear any relation to the agricultural value of these substances. Trade values are determined by the law of supply and demand, and many of the materials used in commercial fertilizers are required by other industries as well, so it is not the agricultural demand alone that sets the price. The agricultural value of a fertilizer is

measured by the value of the increased crop produced by its use, and is, therefore, a variable factor depending upon the availability of its constituents, and the character of the crop to be raised It is possible to have circumstances under which a fertilizer with a comparatively low commercial valuation may have a high agricultural value.

Must Know what Fertilizer is Needed.—It is not sufficient to know how to calculate the commercial value of a fertilizer, and to be able to determine if the price asked is reasonable. One must also know the food requirements of the crop, and the condition of the soil before he can intelligently purchase fertilizers. A piece of land which was deficient in potash, for instance, would not be benefited by the use of a fertilizer which contains little or no potash, but which might be of great value when used elsewhere. In other words, the purchaser who desires to buy that which will give him the best returns must be guided by chemical analysis even more than by the commercial valuation.

Home Mixing the Most Rational Practice.—The idea of mixing the fertilizers on the farm is daily becoming more popular. This is attested by the fact that every year a larger number of dealers in fertilizers are offering for sale the unmixed goods. Already it has been noted that the plant food can be purchased at a lower cost in the basic materials, and that the form of combination is often as important as the actual amounts present. It is only by buying the unmixed goods that one can be certain of the form of the plant food. But aside from these considerations

there is an educational value in the use of the separate ingredients, which is lost when mixed goods are employed. This fact has been aptly stated in a bulletin from the New York station at Geneva, as follows: —"There is little of educational value in using an unknown mixture To purchase intelligently unmixed fertilizing materials will ultimately lead in most cases to a well grounded knowledge of the science of agriculture. One will seek to know what the different forms of plant food are, what they do, from what source they can be obtained, and how he can use them to best advantage He will become to some extent an investigator and will of necessity take a deeper interest in his work His entire system of farming will be lifted to a higher plane, and his more intelligent labor will yield more profitable results."

CHAPTER XXII

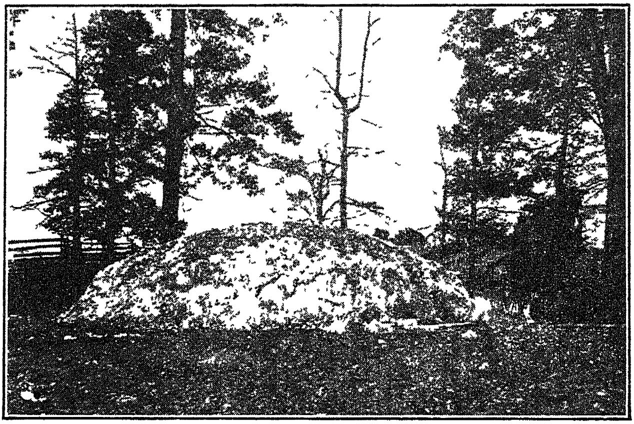
INDIRECT FERTILIZERS

Soil Amendments.—There are a number of substances which are beneficial to the land under some conditions, although they add neither humus nor important quantities of plant food. Such substances have been called **soil amendments,** and the benefit derived from their use arises from the fact that they produce certain changes in the soil, which directly, or indirectly, promote plant growth. Some of these amendments contain small amounts of plant food, but their value is chiefly due to their secondary effect, and not that they add nitrogen, phosphoric acid or potash.

Lime an Important Indirect Fertilizer.—Lime is probably the most important substance of this class, and its use as a manure antedates the Christian era. Although lime has been employed as a fertilizer for so long a time, it is only in recent years that its action has been explained, and at the present time there remain for investigation many questions concerning the action of lime upon the soil.

In a few instances lime has a direct manurial value, for occasionally a soil is found which is so lacking in this substance that the crops are unable to obtain sufficient lime for a maximum yield. Such soils are rare, and in nearly every instance the good results from the use of lime are due to its indirect effect. The effects of lime may be considered to be of three kinds, *i. e.,* physical, chemical and biological.

Lime Improves Physical Condition of Soil.—Lime has a very marked effect on the physical condition of the soil. When added to the sandy soil it tends to make the soil more compact by partially cementing together the particles of sand, and thus makes the soil capable of retaining larger quantities of water. When



A home-made lime kiln for burning lime. The limestone was placed on a pile of wood and the whole covered with sod and earth

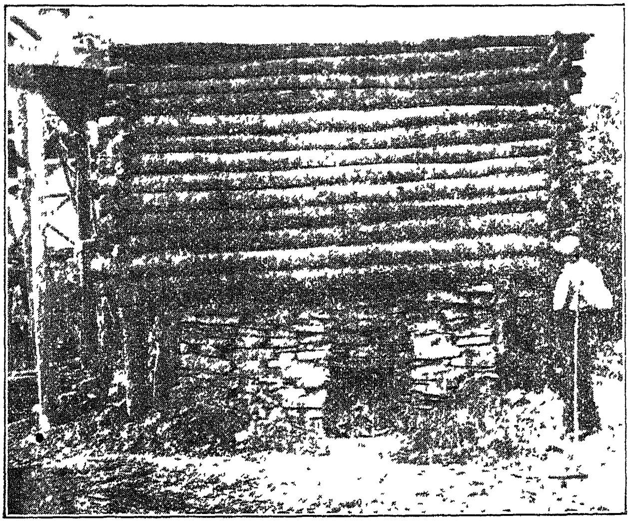
used on clay lands, on the other hand, lime makes the soil more mellow. A clay soil containing very little lime is made fine with greatest difficulty; it adheres to the implements used when wet, and cracks when allowed to dry. A soil rich in lime crumbles more easily, is readily brought into good tilth, and does not adhere to any appreciable extent to the implements. The addition of lime to a soil containing much clay makes the soil more friable, makes it possible for the

rains to percolate more easily through the soil, and overcomes the danger of puddling. The puddling of clay soils is due to the fact that the clay is composed of very small granules which fit so closely together that the water cannot pass between. When lime is added to the soil a number of these small particles become cemented together to form a much larger granule, and as the granules increase in size the spaces between them also become larger.

Any one can easily satisfy himself in regard to this valuable effect of lime on stiff clay by taking a sample of such clay, adding a little water, working it thoroughly, and then allowing it to dry, when it becomes as hard as a brick. If to another portion of the clay a little lime is added (say 1½ per cent.), and this is moistened, mixed thoroughly, and allowed to dry, it will be found that a mere touch will cause it to crumble to pieces There are other materials that have a somewhat similar effect on clay, but none are so efficient as lime. This granulated condition of clay soils, so easily accomplished by liming, is not readily destroyed but will last for some years.

Lime Makes Potential Plant Food Available.—Lime is useful in making potential plant food available. Much of the potash of the soil, for instance, is locked up in insoluble compounds, and is not available to the plant. Lime may decompose these compounds, and thereby convert the potash into forms that the crop can use. Experiments have proved that when lime is applied to a soil originally poor in this constituent the plants grown are not only richer in lime, but also in potash. The use of lime, then, may for a time have a

similar effect to that of potash-containing manures, but it must be remembered that the lime does not supply potash, it merely makes that present in the ground available, and if the store of potash originally present is small, the soil will probably need liberal potash ma-

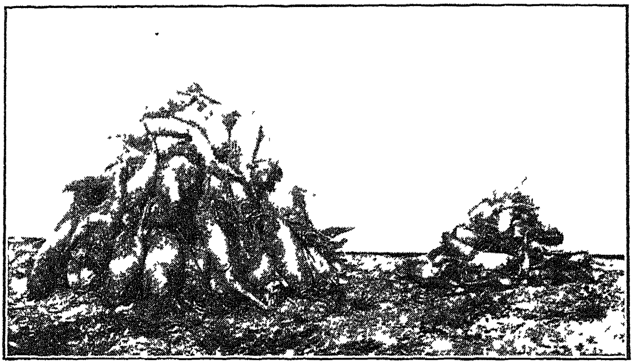


Another home-made lime-kiln lined with sandstone. Limestone and coal are added each day at the top, and the burned lime raked out from the bottom

nuring at an earlier date because of liming. Caustic lime acts energetically upon organic matter, and its beneficial action on peaty or other soils containing large quantities of undecomposed vegetable matter may be partly due to this fact.

Lime Promotes Growth of Desirable Bacteria.—Lime is valuable because it promotes the growth of desirable bacteria in the soil. It has been shown that

one of the most important changes in the soil due to bacterial action is the process of nitrification. The nitrifying bacteria cannot thrive in a soil that is deficient in lime These bacteria are injured by acidity, so it is necessary to keep the soil sweet to promote their action On the other hand, the injurious process



Beets grown on acid soil. The lot to the left on a plot to which lime was added while that on the right was unlimed

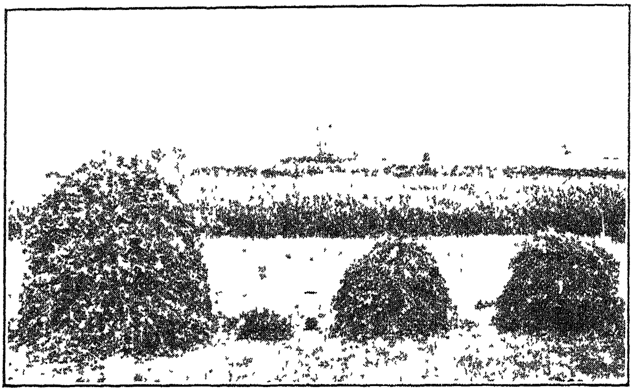
of denitrification takes place more readily in sour soils, so that lime in promoting the desirable process overcomes the undesirable. The bacteria which grow in the nodules found on the roots of the legumes and which "fix" the nitrogen of the air will not perform their functions in an acid soil, so that lime in keeping the soil sweet promotes the gathering of nitrogen by the leguminous plants. In general it may be said that all the desirable fermentations in the soil are accelerated by the presence of lime.

Lime Makes Sour Soil Sweet.—Recent investigations have shown that many soils fail to produce good

crops because they are acid or **sour.** Formerly it was supposed that only low lying or marshy land ever became sour, but experiments conducted by the American stations have demonstrated that there are large areas of uplands where an acid condition of the soil exists. Acidity of the soil is injurious to nearly all of the cultivated crops, so that good returns cannot be expected from sour lands Where such a condition exists the liberal use of lime is the proper remedy. Acidity may result from a number of causes such as the presence of stagnant water, turning under large quantities of organic matter, constant use of commercial fertilizers, etc, but whatever the cause lime is the practical neutralizer. An acid condition of the soil can sometimes be foretold by observation of the character of the plant growth thereon. Where such plants as the common sorrel, beard grass, rushes and mosses grow to the exclusion of the more desirable plants it is a pretty sure indication that the soil is acid, for the plants named are not injured by acidity, while the others are.

Testing Soil for Acidity.—One of the best methods for testing the soil for acidity, is, what is known as, the litmus paper test The test is applied as follows: A little of the surface soil is scratched aside and the piece of litmus paper pressed on the moist soil beneath. If after some time the paper turns a reddish color it shows that the soil is sour. To obtain good results, only the best **neutral** litmus paper should be used. The directions given for making this test are often misleading One frequently sees such a statement as this: "Test with blue litmus paper. This can be bought

at a drug store for a few cents," etc. As a matter of fact, the blue litmus paper usually found in the retail stores is worthless for this purpose. It is not sufficiently sensitive to acid, and an amount of acid, that would prevent the growth of clover entirely might not change the color of this common litmus paper at



Effect of liming acid soils on growth of clover. The large pile on the left was grown on the limed plot, the very small pile next to it being weeds. The second pile from the right shows the clover, and the pile on the extreme right the weeds from a plot of the same area which received no lime

all. One who contemplates making the test should be sure to obtain a sample of extra sensitive neutral litmus paper, which the druggist can procure for him if he does not keep it in stock.

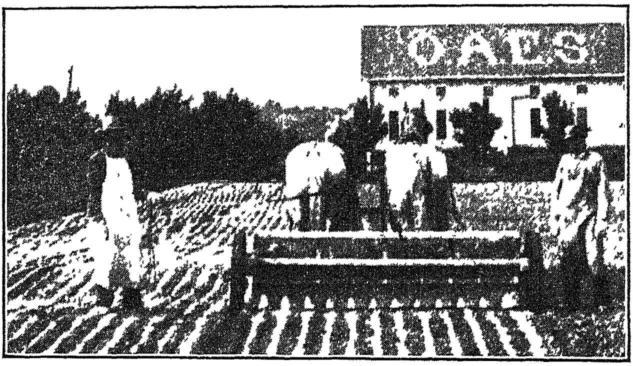
Clover as an Indicator.—The clovers and other leguminous plants require more lime than do the cereals, and are much more sensitive to acidity of the soil. A good stand of clover, therefore, is an indication that the soil contains sufficient lime. If, on the other hand

the clover, after taking root in the spring, is found later in the season to be making no growth, and finally to disappear, the indications are that the soil is acid and that an application of lime will be beneficial. In a great many cases the failure of clover has been shown to be due to acidity of the soil. The best way for determining the need of lime is by means of a plot test as described for commercial fertilizers. Soils derived from granite, slate or shale are prone to be deficient in lime.

Kind of Lime to Use.—Lime has been used on the soil in the various forms of quicklime, hydrated lime, slaked lime, marl and ground limestone If the lime is used to improve the physical condition of heavy clay soils quicklime is undoubtedly the best form to apply to the soil. More often the lime will be used to correct acidity, and in this case the best form to use is probably that which can be most cheaply obtained and applied, keeping in mind the fact that about two tons of ground limestone or marl will be required to furnish as much actual lime as one ton of quicklime. Finely ground limestone is apparently coming into high favor for correcting the acidity of soils, and where it can be obtained at a sufficiently low cost is undoubtedly the safest form to use, especially by the inexperienced. In some experiments the ground limestone has given better results than quicklime.

Applying Lime.—As the lime is gradually carried downward in the soil it should always be applied to the surface, and if possible thoroughly incorporated with the few upper inches of the soil. From one-half to one and one-half tons of lime an acre (or twice as

much ground limestone), applied once in five or six years is usually sufficient. Lime cannot be handled in the ordinary fertilizer drill, as it packs above the feeder and fails to run out evenly, and these drills will not apply the lime in sufficient quantity. Satisfactory special lime drills are on the market. Ground limestone can be broadcasted from the wagon, but slaked lime



Applying lime to the soil. The lime drill should be followed by the harrow

is a disagreeable material to handle in this way. Either substance can be applied with an ordinary manure spreader by first covering the bottom of the spreader with litter to prevent the material from sifting through. In any case the lump lime must first be slaked.

Another way of applying lump lime is to distribute the freshly burned lime in small piles over the field, throw a little water on the lime and cover with earth. After the lime has slaked, mix it with more earth and spread with the shovel. Half a peck to the square rod would give about 1,400 pounds to the acre As a gen-

eral rule quicklime should be used only in the autumn, while ground limestone may be applied at any time. Lime should never be mixed with commercial fertilizers, yet the best results will be obtained from commercial fertilizers on a soil that is abundantly supplied with lime.

Lime not a Universal Remedy.—So many articles are appearing in the agricultural press describing the benefits of liming the land that there is some danger of exaggerating its importance No investigations in agriculture of recent years have led to better results than those on the use of lime, but one must not lose sight of the fact that there are many soils which would not be at all benefited by the addition of lime, and that in some instances the use of lime actually resulted in a decreased crop. It must be remembered that lime adds no plant food to the soil, but simply brings about conditions which enable the crop to use larger quantities of the food already present, so that if used alone it makes the exhaustion of the soil the more rapid. Lime can in no way take the place of good tillage, or the use of manure, green manures or fertilizers. There is an old saying to the effect that "lime makes the father rich, but the son poor," and this is undoubtedly true if lime is used alone It has, however, a legitimate place in agriculture, and if used in connection with green crops, barnyard manure and commercial fertilizers will in many cases produce beneficial results. Lime should never be used immediately before a crop of potatoes, as it has a tendency to increase the scab if the land or seed is infected with the scab-producing organism It is probably best applied to clover in the rotation.

Marl.—In many places are found beds of marl of considerable size. Most of the marls are formed from shell deposits, and consist of carbonate of lime of more or less purity. As marl is practically the same as ground limestone, it has the same effect on the soil, and is a convenient form in which to use lime when obtainable at reasonable cost. Some of the European marls contain appreciable quantities of potash and phosphoric acid as well, but the American marls are of value only for the lime they contain.

Gypsum or Land-Plaster is a compound of lime with sulphuric acid (sulphate of lime) and has been used for many years as a fertilizer. For a long time the action of land-plaster was little understood, but it is now generally believed that its beneficial action is due to the fact that the plaster sets free the unavailable potash of the soil, and for this purpose it is more useful than lime. It is of value to those crops that are benefited by the use of potash manures and, as will be surmised, plaster gives good results only on soils containing large amounts of potential potash. For this reason it gives best returns when used on clay soils and practically no beneficial results when used on sandy soils. The best method of using it is probably to add it to manure as has been suggested When gypsum has been used continually it has been found that after a time it fails to produce satisfactory results. In the latter case it is probable that the crop would be benefited by an application of potash manure. Hilgard has found that gypsum is valuable in removing the so-called black alkali from the alkali soils of western United States.

Salt of Doubtful Value.—Salt was among the first substances to be used as a manure, but in spite of the antiquity of its use the value of salt as a fertilizer is still in dispute It is certain that injury quite as often as benefit has resulted from the application of salt. In fact, it may be said that there are no experiments of any note, which indicate that salt has any beneficial effect on plant growth. Large quantities of salt are poisonous to plants as everyone knows, due undoubtedly to the chlorine that the salt contains. It was formerly supposed that such plants as asparagus were benefited by the application of salt, but investigations have not shown any increase in yield from its use It is well known that salt checks fermentations of all kinds so that it probably decreases the rate of nitrification which is seldom desirable. It is said that adding salt to the land will make the straw of wheat stiffer, but this effect is very likely due to the fact that the salt on account of its poisonous action makes the straw shorter and the greater stiffness is due to reduced length. Many so-called agricultural salts are on the market, but they certainly do not possess any virtues not found in common salt, and it is doubtful if there is any manurial value in salt of any kind.

COMPOSITION OF MATERIALS USED IN THE MANUFACTURE OF COMMERCIAL FERTILIZERS

	Nitrogen per cent	*Phos. Acid per cent*	*Potash per cent*
Dried blood—red	13–14		. .
Dried blood—black	6–12		
Dried meat meal, or azotine	13–14	.	. . .
Hoof meal	10–12	.	. . .
Dried fish	7–8	6–8	.
Tankage	4–9	3–18	.
Leather meal	10–12		.
Sulphate of Ammonia	20–21	. .	.
Nitrate of Soda	15–16	. .	
Raw bone meal	4–5	20–24	.
Steamed bone meal	1–2	25–30	.
Bone black		32–36	
Bone ash		27–36	.
South Carolina rock	.	26–28	. . .
Florida rock		18–30	. .
Tennessee rock		25–32	.
Basic slag (Thomas phosphate)		15–20	. .
Acid phosphate or superphosphate		12–16	. . .
Acidulated bone meal	1–2	12–16	
Kainit	.	.	10–13
Muriate of Potash	. .	. . .	50
Sulphate of Potash	. .	. .	50–53
Low grade sulphate of potash	. . .	. . .	26
Wood ashes	. .	2–4	4–6

COMPOSITION OF FARM MANURES

	Water per cent	*Nitrogen per cent*	*Phos acid per cent*	*Potash per cent*
Cattle, fresh	77.0	0.44	0.16	0.40
Cattle, rotted (in yard) . .	77.2	0.32	0.14	0.47
Cattle, deep stall . . .	73.0	0.64	0.36	0.87
Horse, fresh .	70.0	0.58	0.28	0.53
Horse, rotted	57.0	0.44	0.35	0.49
Pigs, fresh . .	73.0	0.45	0.19	0.60
Sheep, fresh . .	64.0	0.83	0.23	0.67
Sheep, rotted (in yard)	73.0	0.63	0.81	0.44
Human excrements mixed	93.5	0.70	0.26	0.21
Poultry	56.0	1.60	1.50	0.8
Mixed farm manures, fresh	75.0	0.45	0.21	0.52
Mixed farm manures, rotted .	74.0	0.50	0.26	0.63

ERTILIZING CONSTITUENTS OF FARM PRODUCTS AND FEEDING STUFFS

	Pounds in 1000			
	Dry Matter	Nitrogen	Phos. Acid	Potash
lfalfa, green plant	249 0	6 8	1 4	4 5
lfalfa, hay	925 3	22.4	5.1	16 8
pples	158 0	0 95	0 2	1 4
rtichoke, Jerusalem	200 0	2 6	1 4	4 7
sparagus	63 7	3 0	0 8	2.0
tlas meal (see distillery feed)	.	. .	. .	. .
rley, grain	857 0	15 1	7 9	4.8
rley, straw	858.0	5.5	2 0	10.6
rley, green plant	313 7	3 3	2 0	5.1
rley, malt	925 0	16.0	9 3	4.4
rley, malt sprouts	880.0	37 0	17.4	19.9
rley, Brewers' grains (dry)	905 0	33 0	16.1	2.0
rley, Brewers' grains (wet)	237.8	8.1	4 2	0 5
ean, field, seed	857 0	40.7	12 0	12.9
ean, field, hay	840 0	29.6	6 4	20.5
ean, field, straw	816 0	13 0	2.7	18.7
ean, soy, (see Soy bean)	.	. .	. . .	. . .
eet, red	122 7	2 4	0.9	4.4
eet, sugar	180 0	2 1	0.8	3.7
eet, leaves	110.0	3 8	0.9	5 1
lackberries	110.9	1.5	0.9	2 0
ran (see wheat)	.		. . .	. . .
rewers' grains (see barley)	. . .		.	. .
uckwheat, green plant	163.0	4 0	0.7	2.8
uckwheat, hay	840.0	7 7	6 1	24.2
uckwheat, seed	867.0	17 0	6 9	3.0
utter	920 9	1 2	0 4	0.4

FERTILIZING CONSTITUENTS—CONTINUED

	Pounds in 1000			
	Dry Matter	*Nitrogen*	*Phos Acid*	*Potash*
Buttermilk	98.8	6 4	2 2	2 1
Cabbage	110.0	2 4	1 4	5 8
Carrots	130 0	2 0	0 9	2 6
Cauliflower	93 9	2 6	1 6	3.6
Cheese	667 5	39 3	6 0	1.2
Cherries	157 0	1 8	0 6	2 0
Clover, (medium red), green plant	210 0	5 4	1 5	4 8
Clover, hay	842 0	20 7	5 6	18.9
Clover, seed	850 0	30 5	14 5	13.5
Clover, straw	845 0	14 7	4 2	12 6
Clover, (mammoth), hay	886 0	22 3	5 5	12 2
Clover, (crimson), green	185 0	4.5	1 2	4 0
Clover, (crimson), hay	836 0	19 1	3 8	12.4
Clover, (alsike), green	182.0	4 7	1 0	2 1
Clover, (alsike), hay	840.0	21 6	5.0	13.9
Corn, grain, (flint)	879 0	16.6	5 7	3.7
Corn, grain, (dent)	882 0	16.2	5 7	3 7
Corn, bran	909 0	16 3	12 1	6 8
Corn, cobs	875.3	4 2	0.4	4.1
Corn and cob meal	910.4	14 1	5.7	4.7
Corn, green plant	207.0	2.9	1.2	4.0
Corn fodder with ears	921 5	17.6	5.4	8 9
Corn fodder without ears	908 8	10 4	2.9	14 0
Corn, silage	220 5	2.8	1.1	3.7
Corn by-products:				
Germ meal	896 0	26.5	8 0	5.0
Gluten feed	922 0	38 4	4 1	0.3
Gluten meal	914 0	50 3	3 3	0 5

FERTILIZING CONSTITUENTS—CONTINUED

	Pounds in 1000			
	Dry Matter	*Nitrogen*	*Phos. Acid*	*Potash*
ottonseed meal	911 8	69 0	3.0	10 9
ow-peas, green plant	211.9	2 7	1 0	3 1
ow-peas, hay	893 0	26.6	5 2	14.7
ream	259 5	4 0	1 5	1 3
ucumbers	42 1	1 6	1 2	2 5
istillery feed (Atlas)	887 9	53 0	2 3	1 6
ggs	328 0	21 8	3 7	1.5
lax seed	923.0	38 3	20.3	3.[illegible]
erm meal (see corn)	. .	. . .	. . .	. . .
luten meal (see corn)	. .	. . .	. . .	. . .
rapes	170 0	1 6	1.1	2 [illegible]
ops, whole plant	860 0	25 0	5 8	17 9
ops, flowers	880 0	32 2	11.1	23 0
entucky Blue-grass	896 5	11 9	4 0	15 [illegible]
ohl-rabi	119.6	4.8	2 7	4.[illegible]
ettuce	60.1	2 2	0 8	3.[illegible]
inseed meal (see oil meal)	. . .	. . .	. . .	. .
laize (see corn)	. . .	. . .	. . .	. . .
lalt, etc. (see barley)	. . .	. . .	. . .	. . .
langel-wurzel (mangolds)	127.1	1.9	0 9	3.8
leadow hay (mixed)	863 0	14.7	4.1	13 2
liddlings (see wheat)	. . .	. . .	. . .	. .
lilk	128 3	5.1	1 9	1.7
lilk, skim	95.7	5 2	2 1	2 0
lillet, green plant	374.0	6.1	1 9	4.1
lillet, hay	902 0	12 8	4.9	16.9
ats, green plant	166 4	4 9	1.3	3.8
ats, grain	867.0	16.5	6.9	4 8

FERTILIZING CONSTITUENTS—CONTINUED

	Pounds in 1000			
	Dry Matter	Nitrogen	Phos. Acid	Potash
Oats, hay	885 0	11 9	6.7	25 4
Oats, straw	855 0	4 6	2 8	17 7
Oil meal (old process)	910 6	53 2	16.4	13 1
Oil meal (new process)	890 0	56 4	17.4	13.4
Onions	132 2	2 0	0.8	1.7
Orchard grass, green	300 0	3 8	1.3	5.9
Orchard grass, hay	889.0	13.0	3 8	17.7
Parsnips	168.0	1 8	2 0	4.4
Peaches	121 0	1 0	0 5	2.4
Peanut cake meal	896 0	75.6	13 1	15 0
Pears	164.9	0.7	0 4	1.3
Peas (field), green plant	181.0	5 4	1 5	5.1
Peas, hay	850 0	19.4	2.7	6.3
Peas, seed	860 0	36 0	8.4	10.1
Peas, straw	864 0	14 3	3 5	10.2
Plums	343 0	1 8	0.3	2 0
Potatoes, common	250.0	3 4	1 6	5.7
Potatoes, sweet	266.0	2 3	0 9	4.1
Pumpkin	192 0	1.1	1 6	0.9
Radish	67 0	1 9	0.5	1.6
Rape	145 0	4 5	1 5	3.6
Red-top hay	917 0	12 0	3 6	10.2
Ruta-bagas	109 0	1 9	1 2	4 9
Rye, grain	857 0	17 6	8 5	5.8
Rye, green plant	234 0	5 3	2 5	7.1
Rye, straw	864 0	4.9	2 5	8.6
Rye-grass hay	880.0	20 8	7.6	24.6
Sainfoin hay	845.0	21.2	4 6	13.2

FERTILIZING CONSTITUENTS—CONTINUED

	Pounds in 1000			
	Dry Matter	*Nitrogen*	*Phos. Acid*	*Potash*
Serradella hay	870.0	24.3	8.4	31.9
Sorghum seed	866.0	14 6	8.1	4.2
Sorghum, green plant	178.0	2 3	0 9	2 3
Soy beans, hay	937 0	23.2	6.7	10.8
Soy beans, seed	900.0	53 6	14.5	16.2
Soy beans, straw	840.0	11 8	2.9	4.8
Spinach	86.4	4.9	1.6	2 7
Strawberries	94.8	1.5	0.8	1.8
Sugar beets (see beets)	...	...	...	...
Timothy, green plant	331.0	4.8	2.6	7 6
Timothy, hay	863 0	9.7	5.0	14.1
Tobacco, leaves	820 0	24.5	6.6	40.9
Tobacco, stalks	938.0	37.0	6 5	50.2
Tobacco, stems	820 0	25.0	9.2	60 0
Tomatoes	63.6	1.6	0.5	2.7
Turnips	92.0	1.9	0.9	3.4
Vetch (hairy), green plant	175 0	5.1	1.2	4.3
Vetch, hay	840.0	36 8	9.7	24.4
Vetch, seed	840.0	37.0	9.6	8.4
Vetch, straw	850.0	10 9	2.7	6.3
Wheat, bran	883.0	26.7	28.9	16.1
Wheat, grain	866.0	19.3	8.7	5.5
Wheat, green plant	233.0	5.4	1.5	7.0
Wheat, middlings	874.0	22.8	13.5	7.4
Wheat, shorts	882.0	28.2	13.5	5.9
Wheat, straw	857.0	4.8	2.2	6 3
Whey	66.2	1.4	1.1	2.0

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